

Eustachian Tube Function in Healthy Children

A pressure equilibration study
with an adult reference group

Anita Bylander



Malmö 1983

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EUSTACHIAN TUBE FUNCTION IN HEALTHY CHILDREN

A pressure equilibration study
with an adult reference group

by

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- Is there any theory that is new
can tubal impairment be true? -
(In the spirit of S.I.)

The present thesis is based on the following publications, which will be referred to by their Roman numerals.

- I. Bylander, A., Ivarsson, A. & Tjernström, Ö.
Eustachian tube function in normal children and adults.
Acta Otolaryngol (Stockh) 92, 481, 1981.
- II. Bylander, A., Tjernström, Ö. & Ivarsson, A.
Pressure opening and closing functions of the Eustachian tube in children and adults with normal ears.
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- III. Bylander, A., Tjernström, Ö. & Ivarsson, A.
Pressure opening and closing functions of the Eustachian tube by inflation and deflation in children and adults with normal ears.
Acta Otolaryngol (Stockh). In press, 1982.
- IV. Bylander, A. & Tjernström, Ö.
Changes in Eustachian tube function with age in children with normal ears. A longitudinal study.
Acta Otolaryngol (Stockh). In press, 1982.
- V. Bylander, A.
Upper respiratory tract infection and Eustachian tube function in children.
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ABBREVIATIONS AND DEFINITIONS

Middle ear disease = all types of otitis media including
acute otitis media, middle ear effusion,
chronic otitis media, retraction pocket
cholesteatoma, and adhesive otitis

MEE = middle ear effusion = collection of fluid in the
middle ear cavity

URI = upper respiratory tract infection

Muscular opening function(active pressure equilibration function)

Exhalation = airflow from the middle ear

Inhalation = airflow to the middle ear

Pressure opening function(passive pressure equilibration function)

Deflation = airflow from the middle ear

Inflation = airflow to the middle ear

Inflationary manoeuvres

Valsalva's manoeuvre = forced expiration with open glottis
against occluded nose and mouth

Mouth-to-nose inflation = blowing by the mouth through a
catheter linked by a nose olive
to one of the nostrils, the other
one occluded

Deflationary manoeuvres

Sniffing = forceful nasal inspiration with closed mouth

Reversed Valsalva's manoeuvre = forced inspiration with closed
mouth against occluded nose

Pressure symbols

Pol	Pressure opening level
Pol _{ch}	Overpressure in the middle ear forcing the tube open by deflation in a pressure chamber
Pol _{rh}	Rhinopharyngeal overpressure forcing the tube open by Valsalva's manoeuvre or, if not measurable, by mouth-to-nose inflation
Pcl	Pressure closing level
Pcl _{ch}	Overpressure in the middle ear when the tube is closed after deflation in a pressure chamber
Pcl _{rh}	Overpressure in the middle ear when the tube is closed after Valsalva's manoeuvre or, if not measurable, after mouth-to-nose inflation

Pressures are expressed in kPa (1 kPa ~ 10 cm H₂O) and are relative to ambient pressure.

INTRODUCTION

The etiology and pathogenesis of middle ear disease are still largely unknown despite numerous clinical and experimental investigations in this field. Ever since Politzer (1878) suggested that underpressure in the middle ear, due to dysfunction of the Eustachian tube, is the causative factor, this *ex vacuo* theory has been repeatedly discussed. It is now generally accepted that tubal dysfunction is involved in these disorders and especially in middle ear effusions (MEE). Many authors have regarded this impairment as the most important causative factor (Politzer, 1878; van Dishoeck, 1941; Silverstein et al., 1966; Bluestone et al., 1972; Renvall & Holmquist, 1974; Cantekin et al., 1976). This conception was based on clinical observations and investigations, in which tubal dysfunction was found in subjects with middle ear diseases. So far, however, there is no conclusive evidence that the dysfunction is a primary etiologic factor. On the contrary, the impairment might be secondary to the middle ear disease.

Further support for the *ex vacuo* theory as a pathogenic mechanism in MEE has been demonstrated in several studies of experimental tubal obstruction in animals (Holmgren, 1940; Sadé et al., 1959; Lim & Hussl, 1970; Paparella et al., 1970; Proud & Odoi, 1970; Arnold & Vosteen, 1975; Cantekin et al., 1977; Tos, 1981). The experimental observation that simultaneous Eustachian tube occlusion and ventilation through a tympanostomy tube did not cause MEE provides further evidence for this theory (Proud & Odoi, 1970; Arnold, 1972).

Infection of the middle ear mucosa rather than dysfunction of the Eustachian tube has also been suggested as a cause of MEE (Zöllner, 1942; Suehs, 1952; Senturia et al., 1958; Sadé, 1966). The current opinion about the infectious etiology is that MEE is caused by an inflammatory process in the middle ear, less virulent than the acute otitis media, or by an immunologic reaction mediated by pathogenic antigens (Liu et al., 1975; Veltri & Sprinkle, 1976; Giebink et al., 1980; Palva et al., 1981; Juhn, 1982; Lim & DeMaria, 1982). Some authors have also found signs of allergic reaction in MEE (Jordan, 1949; Miglets, 1973; Reisman & Bernstein, 1975; Alm et al., 1982).

Knowledge of the normal physiology is a prerequisite for the comprehension of pathophysiological mechanisms. To evaluate the role of the Eustachian tube in middle ear disease it is thus necessary to study the tubal function in normal subjects. Description of the normal physiology of the Eustachian tube with the aid of different pressure equilibration tests has so far only been made in adults (Elner et al., 1971; Groth et al., 1980). Since middle ear disease is more common in childhood it is important to acquire knowledge also about the normal physiology of the tube in children.

Available methods for quantitative measurements of the tubal function generally require a perforated eardrum, which might affect the normal physiology of the tube and middle ear system (Cohn, 1977). Thus, a prerequisite for comparison between results under normal and pathological conditions is methods and test procedures by which it is possible to assess the Eustachian tube function in subjects with intact eardrums. This is also desirable for ethical reasons. Furthermore, when evaluating tubal function in healthy children it is considered valuable to study healthy adults with the same method at the same time in order to get a reference group.

It is probable that difficulties in finding reliable and non-traumatic methods and in selecting cooperative and otologically healthy children by strict definition explain the lack of previous investigations.

REVIEW OF LITERATURE

DIFFERENCES IN THE EUSTACHIAN TUBE ANATOMY BETWEEN CHILDREN AND ADULTS

The Eustachian tube is a slit-like funnel, which connects the middle ear with the rhinopharynx, and is lined with a pseudo-stratified columnar ciliated epithelium. At birth the tube is almost horizontal. Thereafter it gradually slopes downwards because of growth changes in the base of the skull and the facial cranium. At about 4 years it forms an angle of about 20° to the horizontal plane, in the adult the angle is about 40° . As the skull grows the tube elongates from about 17 mm at birth and 30 mm at 6 years to a total length of 31-38 mm in the adult. The tympanic part comprises one third, and the pharyngeal fibrocartilagenous part two thirds of the tube (Graves & Edwards, 1944; Proctor, 1967; Holborow, 1970). The junction between these parts, the isthmus, is the narrowest part of the tube and its diameter is smaller in children (about 2.4×0.7 mm) than in adults (about 4.3×1.7 mm) according to Lim (1974). In infancy the levator veli palatini muscle is separated from the medial lamina of the tubal cartilage and may therefore have little action on the tube. As the medial lamina lengthens and the tube rotates into its more adult position the levator progressively gains more contact with the cartilage. Furthermore, the submucosal glands surrounding the Eustachian tube show a marked decrease with age (Holborow, 1970, 1975; Tomoda et al., 1981a). The elastic component of the tubal cartilage is more pronounced in adults than in children (Aschan, 1955; Guild, 1955). The submucosal connective tissues are underdeveloped in fetal tubes and its number of elastic fibres increases with age (Tomoda et al., 1981b).

PHYSIOLOGY AND FUNCTIONAL TERMINOLOGY OF THE EUSTACHIAN TUBE

The functions normally attributed to the Eustachian tube are: 1) equilibration of the middle ear pressure; 2) drainage of the middle ear; and 3) protection from respiratory pressure differences, sound, rhinopharyngeal secretions and ascending pathogenic agents. The pressure equilibration function and the

drainage function make demands upon tubal opening ability, while the protective function is dependent on the closing ability.

Normally, the Eustachian tube is in a state of collapse throughout its cartilagenous portion and opens by the intermittent muscular activity at deglutitions (Toynbee, 1853; Perlman, 1939). Opening by muscular action can also be achieved by yawning, chewing, opening of the mouth and other mandibular movements (Rich, 1920). A few subjects can obviously open the tubes voluntarily without any visible jaw movements (Perlman, 1939), probably by contracting pharyngeal or palate muscles, thus indirectly affecting the primary tubal opening muscles. Respiratory movements alone will not open the tube, nor does it seem to be affected by mouth-breathing, phonation or simple elevation of the soft palate (Perlman, 1951).

A normal adult equilibrates the air pressure between the rhinopharynx and the middle ear by swallowing about once a minute awake and once every five minutes when asleep (Graves & Edwards, 1944). However, the Eustachian tube does not open at every deglutition (van Gyergyay, 1932; Perlman, 1951; Aschan, 1955). The tensor veli palatini and the levator veli palatini are the main muscles considered to be associated with tubal opening (Toynbee, 1853; Zöllner, 1942; Aschan, 1955; Proctor, 1973). Recent studies have confirmed earlier reports (Rich, 1920) that the tensor veli palatini is the only muscle which opens the entire tube (Riu et al., 1966; Rood & Doyle, 1978; Cantekin et al., 1979a; Honjo et al., 1979).

The motor innervation of the tensor veli palatini is supplied by the third branch of the trigeminal nerve (Rich, 1920). The motor innervation of the levator veli palatini muscle is still being discussed. Rich (1920) suggested both trigeminal and glossopharyngeal supply, while Dickson (1976) found trigeminal innervation alone. The sensory innervation of the tube is derived mainly from the tympanic plexus of the glossopharyngeal nerve. As regards the autonomic innervation three types of nerves (adrenergic, cholinergic and VIP-containing) were found in the subepithelial layer, around the acini of the seromucous glands, and around blood vessels. It was suggested that these nerve fibres take part in the regulation of the patency of the tube by controlling the local blood flow and the secretion from the

tubal glands (Uddman et al., 1979).

In the following discussion, the different muscular activities causing tubal opening will be called the *muscular opening function*. Traditionally it is regarded as the most important function, equilibrating the underpressures created in the middle ear under normal conditions due to the slow continuous absorption of gases of the middle ear mucosa (van Dishoeck, 1941; Riu et al., 1966; Ingelstedt & Jonson, 1967; Elner, 1972).

A muscular opening dysfunction is generally assumed to be the direct and commonest cause of negative middle ear pressures, which may lead to MEE according to the *ex vacuo* theory (Politzer, 1878). It has also been suggested that intratympanic underpressures are caused by swallowing with occluded nose, i.e. Toynbee's manoeuvre (1853), sniffing (Gray, 1967; Lamp, 1973; Ekvall & Magnusson, 1977; Magnusson, 1981a), by mucociliary activity in the tubal mucosal lining (Murphy, 1979), or by a "pumping function" of the tensor veli palatini muscle (Honjo et al., 1981).

Tubal opening can also be achieved by a pressure gradient between the middle ear and the rhinopharynx (Hartmann, 1879; Armstrong & Heim, 1937). When the pressure difference exceeds the tubal resistance the tube will be forced open without any simultaneous contraction of the tubal opening muscles. This passive opening will be called the *pressure opening function*.

Combined effects of these opening mechanisms may occur, i.e. a small positive pressure gradient over the tube will facilitate an insufficient muscular opening function (Perlman, 1967; Ingelstedt, 1981). It is also discussed whether an underpressure in the middle ear may facilitate an active muscular opening by pressure-dependent reflex mechanisms (Flisberg, 1966; Holborow, 1975; Misurya, 1976; Eden, 1981; Guindi, 1981).

The terminology previously used to denote air passage to and from the middle ear is confusing. For this reason Ingelstedt (1981) proposed a standardized nomenclature for the different tests in relation to the air passage through the tube which is used in the present study. The basis for the terminology is a) whether or not the tube is opened by tubal muscles and b) the direction of airflow through the tube. The terms *inhalation*

and *exhalation* are used to describe an airflow to or from the middle ear, e.g. equilibration by an under- or overpressure, respectively, achieved by muscular opening activity. The terms *inflation* and *deflation* describe airflow to and from the middle ear, respectively, achieved by the pressure opening function.

The Eustachian tube closure or closing ability after a passive pressure opening is called the *pressure closing function*. This function is also a passive mechanism and can be expressed as the residual overpressure in the middle ear when the tube is closed after pressure opening.

The drainage function of the Eustachian tube is achieved by 1) active muscular opening of the tube; 2) mucociliary activity of the mucosal lining; and 3) the influence of gravity (Feldman, 1980). Recently, the muscular activity of tubal muscles during clearance has been described as a "pumping function" (Honjo et al., 1981). The drainage function is probably most important during pathological conditions with increased mucus secretion.

The protective function of the Eustachian tube prevents not only respiratory pressure differences and sound, but is also thought to prevent the entrance of secretions and pathogenic agents from the rhinopharynx into the middle ear. This requires a sufficient tubal closing ability. A closing inability or deficiency may result in a patulous tube or closing failure, respectively, i.e. a defective protective function.

METHODS OF TESTING THE EUSTACHIAN TUBE FUNCTION IN SUBJECTS WITH INTACT EARDRUMS

The test procedures available today for measuring the *muscular opening function* of the tube on subjects with intact eardrums are 1) assessment of the middle ear pressure by tympanometry; 2) sonotubometry; and 3) exhalation/inhalation tests.

In recent years middle ear pressure has been indirectly assessed by the acoustic impedance method introduced by Metz (1946) and further adapted for use in a pressure chamber by Thomsen (1958). His observations created the basis for indirect measurements of the middle ear pressure by tympanometry, introduced by Terkildsen & Thomsen (1959) and further described by Jerger (1970) and Lidén et al. (1970). Today, tympanometry is

the most commonly used method for tests of the tubal function in children and is assumed to provide useful information about the muscular opening function of the tube since negative middle ear pressure is considered to reflect an impaired tubal function (Brooks, 1969; Jerger, 1970; Bluestone et al., 1973; Renvall, 1975).

Sonotubometry for evaluation of sound passage via the Eustachian tube from the rhinopharynx to the middle ear at deglutition was introduced by Perlman (1943) and lately refined by Virtanen (1977). In this test an artificial pressure difference across the eardrum is not necessary. It does not seem to be possible, however, to grade the muscular opening function by this test (Andréasson et al., 1983).

The exhalation/inhalation test was introduced clinically by Flisberg et al. (1963a). Ear canal manometry was used on subjects with perforated eardrums to grade the muscular opening function by equilibration of small static pressure differences using deglutitions. Holmquist (1969) introduced the test on subjects with intact eardrums. A pressure gradient across the eardrum was achieved by transmitting over- or underpressures from the rhinopharynx by deglutitions (Holmquist, 1969), or by changing the pressure in the ear canal (Williams, 1975). Thereafter the active pressure equilibration function was recorded by tympanometry. However, these two tests cannot grade the muscular opening function.

By the introduction of a pressure chamber for the exhalation/inhalation test it was possible to induce both positive and negative static pressure differences across the intact eardrum independently of the active pressure equilibration capacity of the test subject (Elner et al., 1971). The microflow technique (Ingelstedt et al., 1967) was initially used for these recordings. This method is unfortunately not suitable for children since the application of the ear probe may be painful.

Münker et al. (1972) described a modified acoustic impedance technique using a differential manometer attached to the ear canal to assess the pressure equilibration capacity during pressure chamber changes. The method could record eardrum movements caused by tubal openings, but quantitative information about the pressure equilibrating capacity was not achieved.

The *pressure opening and closing functions* of the tube can be investigated by inducing relative overpressures either in the middle ear or in the rhinopharynx in order to force the tube open. Using a pressure chamber Hartmann (1879) observed the pressure opening function in subjects with intact eardrums, a function which was further reported by Armstrong & Heim (1937). The pressure opening function has also been studied using Valsalva's manoeuvre (Perlman, 1939; Cantekin et al., 1976; Gersdorff, 1977; Magnusson, 1981a,b), but the rate of pressure application in the rhinopharynx was not taken into account.

EARLIER STUDIES ON THE EUSTACHIAN TUBE FUNCTION IN CHILDREN

Commonly the Eustachian tube function in children has been assessed indirectly by tympanometric measurements of the middle ear pressure. Several authors have reported high negative middle ear pressures or flat tympanograms in the majority of children with MEE and concluded that tubal dysfunction caused the negative pressure (Brooks, 1969; Bluestone et al., 1973; Renvall, 1975). As a consequence, a normal middle ear pressure has been regarded as a reflection of a normal tubal function. However, opinions are still divided as to what is a normal middle ear pressure in children (Brooks, 1969; Bluestone et al., 1974; Renvall et al., 1978). According to Brooks (1969), negative pressures must exceed ≈ 1.7 kPa to be considered truly abnormal.

When screening 3-year-old children by tympanometry, Fiellau-Nikolajsen et al. (1977) and Fiellau-Nikolajsen (1980) demonstrated a high prevalence and spontaneous recovery of underpressures and effusions in the middle ears. Several other tympanometric studies in children of various ages could also demonstrate a high prevalence of MEE, seasonal variations and great spontaneous improvement (Tos et al., 1978; Tos et al., 1979a; Holm-Jensen et al., 1981). In a longitudinal study of 2-year-old children during 2 1/2 years seventy per cent of the ears had pronounced underpressures or effusions in the middle ear on at least one examination (Thomsen & Tos, 1981).

The active pressure equilibration test (exhalation/inhalation test) has also been used for assessing the muscular opening function of the tube in children. Until now all these studies have required a perforated eardrum, so the majority of reports

have concerned children with MEE treated with tympanostomy tubes. Silverstein et al. (1966) reported on 50 such children and found poor muscular opening function in all ears at the initial test and in most ears during the course of treatment over 6 months. Similar results in follow-up studies from 6-30 months using the same exhalation/inhalation technique were reported by Westergaard (1970), Renvall & Holmquist (1974), Briggs et al. (1976), Neel et al. (1977) and Poulsen & Tos (1977). Nevertheless many ears healed satisfactorily and showed normal middle ear pressures after the tympanostomy tubes were extracted (Renvall & Holmquist, 1974; Renvall, 1975; Neel et al., 1977).

In children with MEE and/or recurrent otitis media, treated with tympanostomy tubes, Bluestone et al. (1972, 1974, 1977) and Cantekin et al. (1976) made a comprehensive mapping out of both the muscular opening function and pressure opening and closing functions of the Eustachian tube. They stated that these children had a functional obstruction of the Eustachian tube due to collapse caused by an increased tubal compliance, an inadequate poor muscular opening function, or both. They suggested that children with an initially functional obstruction are more susceptible to intrinsic or extrinsic mechanical factors such as URI or large adenoids resulting in MEE (Bluestone et al., 1977). In addition, Beery et al. (1979) found persistent tubal functional obstruction with no significant change in either the muscular opening function or the pressure opening or closing functions in a longitudinal study over 12-30 months in 27 children with MEE and perforated eardrums. Neither could they demonstrate any relationship between tubal function and the age of the child.

A new method called "the forced response test" has been described (Cantekin et al., 1979b), by which the passive and active tubal resistance to airflow through the tube can be compared in subjects with perforated eardrums. This test has been regarded as more suitable on children with MEE than the exhalation/inhalation test and results from this test have shown that some children with middle ear disease constrict rather than dilate the tubal lumen by swallowing (Bluestone et al., 1982).

Magnusson (1981b) and Falk (1982) found successful sniffing (deflation) to be common in children with adhesive otitis media or retraction pocket cholesteatoma and MEE, respectively. They

proposed that sniffing in combination with a closing failure, leading to a pronounced negative middle ear pressure by locking of the Eustachian tube, was the cause of these disorders.

The Eustachian tube function in healthy children has earlier only been studied by tympanometry (Brooks, 1968; Hopkinson, 1978) or by a tympanometric pressure swallow test (Seidemann & Givens, 1977). Different tubal function tests in the same subject have hitherto only been performed in a few children with traumatic perforations of the eardrum (Cantekin et al., 1976).

AIMS OF THE PRESENT STUDY

1. To make a comprehensive evaluation by different test procedures of the Eustachian tube function in otologically healthy children.
2. To compare the results in healthy children with those in healthy adults tested with the same method.
3. To study the influence of age on the Eustachian tube function in healthy children.
4. To study if there are any differences in the Eustachian tube function between URI and non-URI periods in otologically healthy children.

MATERIAL AND METHODS

The material consisted of 85 children and 92 adults. They were classified as otologically healthy on the basis of the following criteria: no history of recurrent acute otitis media, middle ear effusion, impairment of hearing, or of obstructing adenoid or allergy; no history of recent upper respiratory tract infection (URI); and no symptoms or signs of URI when tested; normal otoscopic or otomicroscopic findings including examination with Siegle's pneumatic otoscope; pure tone hearing thresholds within 0-20 dB (ISO standard 1964); and V-shaped tympanograms indicating air-filled middle ear spaces (Papers I-IV).

During the follow-up of 44 children 3 had one episode of acute otitis media, and one child had two episodes. Furthermore, 7 children had large underpressures (exceeding -2.5 kPa) or even signs of fluid in the middle ears when summoned for retest. Five of them had a history of a recent URI. The children could be tested at the recall after one or two months since they all recovered without intervention during this time. They were therefore not excluded from the follow-up (Paper IV).

The criteria for participation during URI were signs of mucosal swelling in the nose, often with serous or purulent secretion at the ENT-examination and the history provided by the parents (Paper V).

The equipment and performance of the different tubal function tests have been described in detail in the individual papers (I-III) and will only be briefly summarized.

A pressure chamber (3.6 m^3) with a pressure range of $\pm 7 \text{ kPa}$ made it possible to induce static as well as dynamic pressure differences across the eardrum. The application of the static pressure change of $\pm 1 \text{ kPa}$ was performed at a rate of approximately 0.1 kPa/s . The rate of pressure change during the dynamic test was 0.37 kPa/s . For the recordings an impedance bridge (20 70 Madsen Electronics) was used, permitting continuous recording of the compliance. A tubal opening was indicated by a sudden change in the compliance. During all changes in chamber pressure there was free communication through the probe between the ear canal and the chamber.

Before each of the following tests it was checked that the middle ear pressure was equilibrated with ambient pressure either by pressure equilibration of the tube by the test subjects or, if this was not possible, by means of the pressure chamber.

1. *Middle ear pressure* was recorded with tympanometry either performed by pressure changes in the ear canal alone (conventional method) as after the exhalation/inhalation test, or performed by pressure changes in the whole chamber (open tympanometry) as during recording of the pressure closing function.
2. *Muscular opening function* by the exhalation/inhalation test, i.e. active equilibration of a static pressure difference of ± 1 kPa across the eardrum induced by a decrease or an increase in chamber pressure. Depending on the results of an equilibration method of free choice, i.e. by swallowing, yawning and other jaw movements (Paper I), the subjects were divided into tubal function groups I-IV according to Elner et al. (1971). Group I could equilibrate both over- and underpressures completely, and group II partially. Group III could equilibrate overpressure partially but underpressure not at all, and group IV could not equilibrate any pressure applied during the test period. Groups I and II are therefore considered to correspond to good muscular opening function as the airflow passes in both directions of the tube, and groups III and IV to poor function as no equilibration of any negative pressure was recorded during the test period.
3. *Pressure opening and closing functions by deflation in a pressure chamber*. The decrease in chamber pressure required to build up an overpressure in the middle ear sufficient to force the tube open passively was recorded as the pressure opening level (Pol_{ch}). The residual overpressure in the middle ear when the tube closed after the pressure opening was called the pressure closing level (Pcl_{ch}). The child was not allowed to equilibrate by muscular opening during this and the following tests.

4. *Inflationary manoeuvres.* The subject was instructed how to perform Valsalva's manoeuvre and mouth-to-nose inflation. A pressure manometer connected to the system aided the subject in performing Valsalva's manoeuvre correctly. Those who could build up an overpressure in the middle ear by either inflationary manoeuvres, indicated by a change in the compliance curve, were called responders to inflation. The residual overpressure in the middle ear after a successful manoeuvre was recorded as the pressure closing level (Pcl_{rh}), measured by tympanometry 5-10 seconds after the manoeuvre. Irrespective of whether tubal opening occurred or not, the maximal rhinopharyngeal pressure and the rate of induced pressure increase in the rhinopharynx during the inflationary manoeuvre were also calculated.
5. *Deflationary manoeuvres.* The subject was instructed to inspire forcefully with one nostril connected to the pressure transducer, the other open (sniff) or closed (reversed Valsalva's manoeuvre). Those who could achieve a negative pressure in the middle ear by either manoeuvre were called responders to deflation. If the first inflationary or deflationary manoeuvre was unsuccessful, the subjects were instructed to try again twice.

All test procedures in this study were approved of by the Committee for Ethics, University of Lund.

STATISTICAL METHODS

Student's t-test was used for testing significance of mean differences between the normally distributed continuous variables Pol and Pcl. The t-test on paired observations was used when analysing the difference between continuous variables measured on the same individuals (Pol and Pcl over time or by different test procedures). Analysis of variance was used in paper II for comparison of three or more means of continuous variables (Pol and Pcl in different groups). The significance of difference between these groups was calculated according to the method of simultaneous confidence intervals (Scheffe's method). χ^2 -test or Fisher's exact test (for small samples) was used for the comparisons of two or more absolute frequencies or proportions of subjects. This was used for discrete variables (tubal function groups) or not normally distributed ones (middle ear pressure). Sign test was used to verify changes in tubal function groups over time. The correlation coefficient was calculated for continuous variables (Pol and Pcl by different tests and over time).

The test-retest reliability of Pol and Pcl over time presented as mean standard deviation ($\overline{SD}$) was computed by first calculating the square root of the variance of Pol and Pcl measurements on the same ear at the same occasion and then the mean variance for all ears. The standard error of the difference between the measurements was determined according to the formula $\sqrt{2(\overline{SD})^2}$.

RESULTS

MIDDLE EAR PRESSURE BY TYMPANOMETRY

The healthy children had a higher frequency of negative middle ear pressures and pressures within wider ranges than the healthy adults. The middle ear pressures exceeded or were equal to -1 kPa in 18 % of the children despite the fact that they were defined as otologically healthy (Paper I). Furthermore, the middle ear pressures became less negative with increasing ages. This was found both when 85 children of different age-groups were compared (Paper I) and also in 21 single children who were followed up with repeated measurements during 3 years (Paper IV). In the 11 children investigated during URI a significant decrease of the middle ear pressure was found (Paper V).

MUSCULAR OPENING FUNCTION BY THE EXHALATION/INHALATION TEST

The muscular opening function of the tube expressed in tubal function groups I-IV was poorer in the healthy children than in the healthy adults. When only swallowing was allowed for equilibration, 61 % of the 85 children could not equilibrate an underpressure of -1 kPa during 3 minutes as compared with 10 % of the 92 adults. When the subjects were allowed to equilibrate by a method of free choice, i.e. besides deglutitions, opening of the mouth, yawning and other jaw movements during 10-20 minutes, 33 % of the children and 15 % of the adults improved. Although so many children improved by the latter equilibration method, 43 % of the children could still not equilibrate underpressures at all (groups III and IV) as compared with 4 % of the adults. Eighteen per cent of the children could not even equilibrate a positive pressure of 1 kPa (group IV), while all of the adults were able to equilibrate this pressure. Furthermore, the muscular opening function was better in older children than in younger ones (Paper I).

Improvement of the muscular opening function with age was demonstrated in a longitudinal study of 44 children during 1 1/2 - 3 years (Paper IV). The improvement was most obvious during preschool ages (3-7 years), which can also be seen in the distribution of tubal function groups I-IV in the different

age-groups (Papers I and II). In contrast to the findings in children who improved with age the muscular opening function in the 24 adults did not change when followed up during 6-36 months (Paper IV).

During URI the muscular opening function deteriorated to tubal function groups III and IV in 9 of the 11 healthy children investigated. The remaining 2 already belonged to these groups (Paper V).

A significant relation was found between poor muscular opening function and negative middle ear pressures, which confirms the general assumption that a negative middle ear pressure indicates poor tubal function (Paper III).

PRESSURE OPENING AND CLOSING FUNCTIONS BY DEFLATION IN A PRESSURE CHAMBER

There was no difference in the pressure opening and closing levels as measured by deflation in a pressure chamber (Pol_{ch} and Pcl_{ch}) between the healthy children and the adults. As a consequence there were no significant differences between the various age-groups. The Pcl_{ch} was higher in the children with poor muscular opening function than in those with good function (Paper II). Pol_{ch} and Pcl_{ch} did not change during 1 1/2 years in the longitudinal study (Paper IV). During URI both Pol_{ch} and Pcl_{ch} increased in most of the 11 children examined. The increase of Pol_{ch} in 6 children and of Pcl_{ch} in 7 children were significant (Paper V).

PRESSURE OPENING AND CLOSING FUNCTIONS BY INFLATIONARY AND DEFLATIONARY MANOEUVRES

The response rate to Valsalva's manoeuvre was 66 % in the children and 93 % in the adults. The corresponding figures for mouth-to-nose inflation was 60 % and 98 %, respectively. Mouth-to-nose inflation was introduced as a complementary test since in the author's opinion many children failed to perform Valsalva's manoeuvre correctly due to lack of comprehension. However, when a pressure manometer was used, which helped them to perform the manoeuvre, no difference in the response rate between the methods could be observed.

When both Valsalva's manoeuvre and mouth-to-nose inflation were allowed, 100 % of the healthy adults could inflate the middle ears, indicating that earlier failures were due to incorrect technique rather than to tubal dysfunction. Still, only 71 % of the children were successful. Both non-tubal and tubal factors determined the children's response rate to inflation since the responders to inflation created significantly higher overpressures in the rhinopharynx than the non-responders. Furthermore, the non-responders had higher Pol_{ch} and Pcl_{ch} , but the difference was only significant in the case of Pcl_{ch} .

The response rate to deflationary manoeuvres (sniffing and, if unsuccessful, reversed Valsalva's manoeuvre) was 24 % in the healthy children and 34 % in the adults. Despite the use of the pressure manometer the youngest children (3-5 years) were quite unable to deflate. In both children and adults the response rate to deflationary manoeuvres was dependent on tubal factors, which means that it was easier for subjects with low values of Pol_{ch} , Pcl_{ch} and Pcl_{rh} than for those with high values to perform successful sniffing or a reversed Valsalva's manoeuvre. However, in the children also non-tubal factors determined the response rate to these manoeuvres, since non-responders had significantly lower rhinopharyngeal underpressures than the responders. In adults no such difference could be seen.

The rate dependence of Pol_{rh} could be demonstrated in this study, since subjects with higher rates of pressure increase in the rhinopharynx had significantly higher Pol_{rh} than the others. Since the rate of Pol_{rh} was not standardized, unlike that of Pol_{ch} , comparison between these variables was not considered worth while. However, the pressure closing levels (Pcl), reflecting the extra-luminal closing forces of the tube, were approximately of the same magnitude, regardless of whether they were measured after deflations in a pressure chamber (Pcl_{ch}) or after inflationary manoeuvres (Pcl_{rh}). Pcl is thus a rather stable and reliable variable which does not seem to be influenced as much as Pol by the rate of the pressure increase (Paper III).

With one exception, all the children who could deflate their middle ears had a good muscular opening function. Therefore the negative pressures found in the middle ears were considered to be caused by a poor muscular opening function rather than

successful deflationary manoeuvres (Paper III).

In the longitudinal study an increase was observed of the response rate to inflationary and deflationary manoeuvres with increasing age (Paper IV).

During URI the response rate to inflationary manoeuvres decreased from 11 to 4 responders (Paper V).

METHODOLOGICAL CONSIDERATIONS

In investigations of the Eustachian tube function on healthy subjects an intact eardrum is a prerequisite, since a perforation might disturb the normal physiology of the middle ear-Eustachian tube system. Moreover an invasive recording technique of the eardrum does not fulfil ethical demands. The pressure chamber technique used is the only quantitative procedure which permits measurements of both the muscular opening function and the pressure opening and closing functions of the Eustachian tube in subjects with intact eardrums. An analysis of both the exhalation/inhalation and deflation/inflation sequences is considered necessary to elucidate the various mechanisms of the tubal function (Bluestone et al., 1972; Ingelstedt, 1981). The impedance technique was chosen for the recordings since it is simple, reliable, objective, non-invasive as well as atraumatic and therefore useful even in small children.

The magnitude of the applied static pressure difference of ± 1 kPa at the exhalation/inhalation test was chosen, since it has previously been shown to correspond to physiological changes in the middle ear pressures caused by the gas absorption and terrestrial variations in atmospheric pressure (Ingelstedt et al., 1967; Andréasson & Ivarsson, 1976; Ingelstedt, 1981). A higher relative positive pressure in the middle ear increases the risk of a passive pressure opening, and a more negative pressure might facilitate a "locking mechanism", i.e. muscular opening inability due to a suction effect on the mucosal walls in the tube (Flisberg et al., 1963b). Lower pressure differences across the eardrum gave the same results as that of ± 1 kPa (Andréasson & Ivarsson, 1976), and does not therefore seem to be an advantage.

Not only the magnitude of an applied static pressure difference but also the rate of this pressure application would seem to be of importance for getting reliable results (Bluestone et al., 1977). A too abrupt application of negative pressure in the middle ear might affect the outcome because of the earlier mentioned "locking mechanism" (Flisberg et al., 1963b). To avoid this in the present investigation the rate of the pressure change used in the exhalation/inhalation test was approximately 0.1 kPa/s.

In the study of the exhalation/inhalation test, swallowing was initially used for equilibration. However, it was soon observed that a combination with other jaw movements was often more effective in children. These observations triggered a systematic testing of different ways of pressure equilibration called "the method of free choice" including deglutitions, opening the mouth, yawning, chewing and lateral mandibular movements. Coughing, shouting and phonation were also tested but were abandoned since they never caused tubal opening. The results, showing that one third of the children improved by this latter method, stress the importance of investigating the muscular opening function in children by different equilibration methods.

In an attempt to adapt the exhalation/inhalation test to meet with more physiologic demands, the equilibration time by the method of free choice was prolonged up to 20 minutes, 5-10 minutes each for equilibration of applied over- and underpressures, respectively. This extended test period would seem to permit recordings of voluntary as well as reflex opening of the tube. However, all adults and the majority of the children who could open their tubes equilibrated within the first minutes and only a few children were suspected to achieve a reflex opening of the tubes during the latter part of the testing time.

It should be pointed out in conclusion that it is of the utmost importance to standardize the performance of the exhalation/inhalation test. The validity and reliability of this test have been questioned (Bluestone et al., 1977; Cohn, 1977; Poulsen & Tos, 1977; Virtanen, 1977; Magnusson, 1981a). However, one reason that the expected results were not obtained may be that the test was insufficiently standardized.

GENERAL DISCUSSION

Middle ear disease and especially middle ear effusion (MEE) in children is a major everyday problem. MEE is the commonest cause of hearing impairment in childhood. It requires repeated checks owing to its uncertain prognosis and is also a burden economically in medical care because of its high incidence. An adequate pressure equilibration capacity of the Eustachian tube is traditionally considered to be of the greatest importance for preventing the development of MEE (Politzer, 1878; Zöllner, 1942; Bluestone et al., 1972, 1974; Renvall & Holmquist, 1974; Ingelstedt, 1981), even if other etiologies such as infection and allergy are discussed (Alm et al., 1982; Juhn, 1982; Lim & DeMaria, 1982). Furthermore, the available treatment of MEE with decongestants and tympanostomy tubes is mainly aimed at an assumed tubal dysfunction. Despite extensive research there is still no conclusive evidence for the proposed relationship of the Eustachian tube function to middle ear disease in children. Evaluation of the possible role of the tube in children with MEE requires knowledge of tubal function in healthy children. The lack of tubal function studies in such children warrants this investigation.

A crucial point in this study was to provide a definition of an otologically healthy child and to make a selection according to the criteria decided upon. It was difficult to choose suitable children because of the high incidence of upper respiratory tract infection (URI) and middle ear disease in childhood (Tos et al., 1979b; Ingvarsson et al., 1982). A few children with large underpressures with or without fluid in the middle ears in connection with URI were accidentally found during the follow-up but were allowed to remain in the study, since they all recovered without intervention within a month or two when the retest was made.

In consequence of these observations, interest focused on the possible effect of URI on the children's tubal function. The finding that a URI impairs the tubal function even in otologically healthy children stresses the importance of a strictly defined non-URI status in evaluating its normal function.

The results of the exhalation/inhalation test show that the muscular opening function is poorer in healthy children than in

healthy adults and improves with age. The longitudinal study also shows that the improvement is most pronounced during preschool ages. These age-related differences in muscular opening function may be explained by anatomical differences in the shape and position of the skull base, the facial cranium, and the tubal and peritubal structures between children and adults, and also in children of various ages (Graves & Edwards, 1944; Aschan, 1955; Holborow, 1970, 1975; Ross, 1971; Tomoda et al., 1981b; Plester, 1982). This anatomical development with age might improve the muscular vectors crucial for an effective tubal opening. However, a maturing neuromuscular reflex system, activating muscular opening, may also explain the age-related improvement (Holborow, 1975; Eden, 1981). It is also of interest to note that the increasing size of the mastoid air cell system in healthy children (Rubensohn, 1965) parallels the tubal functional improvement.

Healthy adults were included in the present study since it was considered an advantage to have an actual reference group tested with the same method. The results of the different tests in the adults agreed with those of Elner et al. (1971) which confirms the reliability of the present method. When examining children with MEE during treatment with tympanostomy tubes it was found that the muscular opening function was generally poor and remained poor in the majority of children for up to several months (Silverstein et al., 1966; Westergaard, 1970; Renvall & Holmquist, 1974; Briggs et al., 1976; Neel et al., 1977; Poulsen & Tos, 1977; Beery et al., 1979). The present study, on the other hand, shows that about 60 % of healthy children have a good muscular opening function. The difference suggests that tubal dysfunction plays a role in middle ear disease, but conclusive evidence cannot be secured until comparable studies, using the same methods, have been performed.

By using the tubal function groups (I-IV) according to Elner et al. (1971) it was possible to grade the muscular opening function in children and adults and to follow the improvement with age. It is obvious that a poor muscular opening function alone does not always cause MEE, since all children in groups III and IV were otologically healthy and did not develop persistent middle ear disease during the follow-up. On the other hand, most of the children with high underpressures and fluid

in the middle ears, accidentally found during the follow-up or during selection for the URI study, had a poor muscular opening function even when their ears were normal. This may indicate that poor tubal muscular opening function plays a role in the development of MEE.

The exhalation/inhalation test is, however, of limited value when applied to cases in group IV, since it cannot differentiate between a physiologic hypofunction of the muscular opening ability, seen in the children with normal ears, and pathological cases who might never equilibrate. It is suggested that the combined results of this test and the tympanometric findings might further differentiate subjects in this group, since a normal middle ear pressure reveals a sufficient muscular opening function. A great underpressure, on the other hand, might indicate a muscular opening dysfunction of the tube.

Due to the poor muscular opening function in about 40 % of the healthy children (3-12 years) some might probably be able to equilibrate actively only a few times a day, which, however, seems to be sufficient under normal conditions. This infrequent opening pattern may cause transient underpressures which explain the high frequency of negative middle ear pressures seen in the present study. Furthermore, it may explain the varying results of tympanometry in daily repeated tests of single children (Lewis et al., 1975; Schwartz et al., 1978).

The relationship demonstrated in this study between the muscular opening function and the middle ear pressure confirms for the first time the assumption that a negative middle ear pressure indicates a poor muscular opening function (Brooks, 1969; Jerger, 1970; Bluestone et al., 1974; Renvall, 1975). However, it should be stressed that an isolated tympanometric measurement of the middle ear pressure gives only a momentary picture. Repeated measurements are required to assess the tubal muscular opening function by tympanometry.

What should be considered a normal middle ear pressure? The suggested maximum negative middle ear pressure varies from -0.25 to -2.5 kPa (Brooks, 1969; Bluestone et al., 1974; Holmquist, 1974; Harford et al., 1978; Renvall et al., 1978; Lildholdt, 1980). In the present study 1/5 of the children had

underpressures equal to or more negative than -1 kPa and none had negative pressures exceeding -2 kPa. This supports the recent opinions that -1.5 to -2.0 kPa should be the lower limit for a normal middle ear pressure in children (Brooks, 1969; Harford et al., 1978; Renvall et al., 1978).

The pressure opening function is proposed to reflect luminal as well as extra-luminal closing forces of the tube (Zöllner, 1942; Perlman, 1967; Feldman, 1980; Ingelstedt, 1981). The luminal factors include the viscosity and surface tension of the mucus, the blood content and the elasticity of the mucosal vessels (Rapport et al., 1975; Cantekin et al., 1976; Hagan, 1977; Ingelstedt, 1981). Extra-luminal factors, including the elasticity of the tubal cartilage and peritubal structures such as muscles, ligaments and vessels and the peritubal tissue pressure, decide the pressure closing function (Guild, 1955; Cantekin et al., 1979b; Ingelstedt, 1981).

Some of the luminal and extra-luminal components have been reported to change with age (Aschan, 1955; Holborow, 1970; Tos, 1974; Holibka & Holibkova, 1981; Tomoda et al., 1981a, 1981b). However, they do not affect the pressure opening and closing functions, expressed in Pol and Pcl, since in the present study no differences in this respect were found between children and adults, when tested in a standardized manner by means of a pressure chamber. This may be an interesting observation, since Bluestone et al. (1974) assumed that children with MEE have a distensible or "floppy" tube, implying low Pol and Pcl due to a malacia of the cartilage. The results in the case of the healthy children with poor muscular opening function in this study rather showed a mechanical obstruction due to mucosal swelling or a functional obstruction due to a stiff tube, since Pol and especially Pcl increased with poorer muscular opening function predominantly found in the younger children.

Inflationary manoeuvres were assessed in the children and adults from a diagnostic and therapeutic point of view. The response rate to inflation in children was 71 % as compared with 100 % in the adults. The lower rate in children was due to their inability to create a sufficiently high underpressure in the rhinopharynx or high Pol and Pcl. In the absence of knowledge of the magnitude of the rhinopharyngeal pressures, no conclusions

can therefore be drawn as regards the pressure opening and closing functions of the Eustachian tube from inflationary manoeuvres. Valsalva's manoeuvre seems to be useful only after careful instructions and training. Mouth-to-nose inflation is recommended as an alternative especially for small children and for those few adults who cannot master the technique of Valsalva's manoeuvre.

In the present study 34 % of the adults and 24 % of the children were responders to deflation (sniffing or reversed Valsalva's manoeuvre). In the adults, only tubal factors, i.e. low Pol and Pcl, decided the response rate, since they were all able to create sufficiently great underpressures in the rhinopharynx. In children, however, also non-tubal factors decided the response rate to deflation. The inability to create a sufficient rhinopharyngeal underpressure might be due to anatomical and neuromuscular limitations, lack of motivation or difficulty in understanding how to perform a correct manoeuvre.

It has been stated that persistent negative middle ear pressures in children may be caused by sniffing (deflation) rather than absorption of gases in the middle ear in connection with tubal opening dysfunction (Gray, 1967; Lamp, 1973; Magnusson, 1981b). Habitual sniffing associated with a "closing failure", i.e. a deficient tubal closing ability, was observed by Magnusson (1981a,b) in both children and adults with adhesive otitis and retraction pocket cholesteatoma. He proposed that it is more important to focus attention on tubal closing failure than on tubal opening dysfunction and suggested that the sniffing (deflation) test is of value in the definition of risk-groups.

In this study no relation between initial negative middle ear pressure and successful deflation was found, as was the case between negative middle ear pressure and poor muscular opening function. It should be pointed out that successful deflation is not pathological *per se*. However, habitual sniffing in combination with a poor muscular opening function and low tubal closing forces (expressed in low Pol and low or no measurable Pcl) appears to be a possible mechanism in creating a persistent negative middle ear pressure, which might contribute to middle ear disease. Subjects with such characteristics may therefore constitute a risk-group. In the present study the response rate

to deflation varied from time to time but Pcl, measured either after pressure opening in the pressure chamber or after inflationary manoeuvres, proved to be a rather constant and reliable variable. This seems therefore to be a more suitable test in grading the closing ability, i.e. the protective function of the tube. By measuring the Pcl by tympanometry after a successful inflation, e.g. Valsalva's manoeuvre, the closing function can be assessed in clinical practice without the use of a pressure chamber. Low or no measurable Pcl indicates a "closing failure" or a patulous tube, respectively, i.e. a defective protective function, whereas a high value of Pcl precludes this condition.

The results of the present study imply that children generally have a primary muscular opening hypofunction, which is physiologic and improves with age. However, other etiologic or pathogenic factors may aggravate the hypofunction or contribute in other ways to the development and maintenance of MEE. Since also healthy children during URI developed transient episodes of negative pressures and some of them even fluid in the middle ears, it is conceivable that there are no strictly otologically healthy children. However, it is suggested that these transient cases of MEE, which heal spontaneously, should not be regarded as having a disorder of the middle ear. Except for an expectant attitude there is as yet no method by which it is possible to separate these cases from the recurrent or persistent ones or from those pathological ears which will end up with chronic otitis. Not until quite comparable studies in children with and without different types of middle ear disease have been performed will it be possible to determine whether it is feasible at all to separate transient cases from pathological ones with the aid of tubal function tests. Further investigations with the present method on children with middle ear disease but in a free interval are in progress in order to find out if the Eustachian tube is a primary causative factor or only an additional factor in maintaining middle ear diseases in children.

SUMMARY

The normal physiology of the Eustachian tube in children is only partly known. The aim of the present study was therefore to investigate both the active and passive pressure equilibration capacity of the Eustachian tube in a group of otologically healthy children, with otologically healthy adults as a reference group. The impedance technique in a pressure chamber was used for the measurements since it is the only non-invasive method available for quantitative measurements on children with intact eardrums.

The active pressure equilibration capacity, i.e. the muscular opening function of the tube, using swallowing and/or jaw movements was poorer in the children (3-12 years) than in the adults but improved with increasing age, as confirmed by repeated measurements during 3 years. The improvement, which was most pronounced between 3-7 years, is suggested to be due to growth related anatomical changes and a simultaneous neuromuscular maturity. The muscular opening function was improved in 1/3 of the children and in 1/7 of the adults when jaw movements besides swallowing were used, indicating the importance of thoroughly standardized testing methods.

A poor muscular opening function alone does not necessarily cause MEE, since all the children in this study with poor active function were otologically healthy and did not develop persistent middle ear disease during the follow-up. On the other hand, the children with pronounced underpressures or fluid in the middle ears, accidentally found during the follow-up, had a poor muscular opening function even when their ears were normal. This may indicate that poor muscular opening function plays a role in the development of MEE.

The middle ear pressures were lower and showed wider ranges in the children than in the adults. One fifth of the children had middle ear underpressures equal to or exceeding -1 kPa, despite the fact that they were defined as otologically healthy. It is suggested that the lower limit of normal middle ear pressure by tympanometry in children should be -2 to -1.5 kPa.

There was a significant relation between low tympanometric middle ear pressure and poor muscular opening function which confirms the general assumption that a negative middle ear

pressure indicates poor tubal function. However, an isolated tympanometric middle ear pressure gives only a momentary picture and repeated measurements are required to assess the tubal muscular opening function by tympanometry.

The passive pressure equilibration capacity, i.e. pressure opening and closing functions of the Eustachian tube which reflect its closing forces and thereby its protective function did not, however, differ between children and adults and did not change over time in the children when measured at a standardized rate of pressure change in a pressure chamber.

All the adults could inflate their middle ears by Valsalva's manoeuvre or mouth-to-nose inflation. The children who failed achieved significantly lower rhinopharyngeal pressures during inflation and had higher passive pressure opening and closing levels by deflation in the pressure chamber than those who were successful. The pressure closing level of the Eustachian tube was found to be a rather stable and reliable variable, which can also be measured without the aid of a pressure chamber. The ability to establish underpressure in the middle ear by deflationary manoeuvres either with open nose (sniffing) or occluded nose (reversed Valsalva's manoeuvre) was related to low pressure opening and closing levels and in the children also to the rhinopharyngeal underpressure achieved by the manoeuvre. Response to deflation leading to negative middle ear pressure is not pathological *per se*, but if combined with low pressure opening and closing levels and a poor muscular opening function it may constitute a mechanism for creating persistent underpressures in the middle ear which might contribute to middle ear disease.

When a group of the otologically healthy children were examined during a URI they showed deterioration in both the active and passive pressure equilibration functions and lowered middle ear pressures. These changes in the Eustachian tube function may explain the high frequency of transient episodes of underpressures in children with or without fluid in the middle ears. In the many children with a physiological tubal hypofunction due to a primary poor muscular opening function URI may contribute to persistent cases of MEE.

ZUSAMMENFASSUNG

Die normale Physiologie der Ohrtrompete bei Kindern ist grossenteils unbekannt. Die Absicht der hier vorliegenden Arbeit war deshalb, sowohl die aktive als auch die passive druckausgleichende Fähigkeit der Ohrtrompete bei einer Gruppe Kinder, bei denen die Ohren gesund waren, und einer Referenzgruppe, die aus Erwachsenen mit gesunden Ohren bestand zu studieren. Die Messungen wurden mit der Impedanzmethode und einer Druckkammer ausgeführt, die Messungen an Individuen mit intakten Trommelfellen, eine basale Voraussetzung für das Studium der Normalphysiologie der Ohrtrompete, ermöglicht.

Die aktive Druckausgleichsfähigkeit der Ohrtrompete mit Schlucken und/oder Kiefergelenkbewegungen war bei Kindern schlechter als bei Erwachsenen, verbesserte sich aber mit zunehmendem Alter. Dies wurde durch wiederholte Messungen unter einer Zeitperiode von drei Jahren bestätigt. Es wird vorgeschlagen, dass die Verbesserung, die am deutlichsten im Alter zwischen drei und sieben Jahren war, auf wachstumsmässigen anatomischen Veränderungen und einer gleichzeitigen neuromuskulären Reife beruht. Die aktive Druckausgleichsfähigkeit mit Schlucken wurde bei 1/3 der Kinder verbessert, wenn auch Kiefergelenkbewegungen angewendet wurden; dies zeigt die Bedeutung genau standardisierter Testmethoden.

Der Mittelohrdruck war niedriger und zeigte bei Kindern verglichen mit Erwachsenen grössere Verbreitung. Es bestand eine signifikante Relation zwischen niedrigem Mittelohrdruck und schlechter aktiver Druckausgleichsfähigkeit. Ein Fünftel der Kinder hatte in den Mittelohren einen Unterdruck von -1 kPa oder mehr, trotz der Tatsache, dass sie als ohrengesund definiert waren. Es wird vorgeschlagen, dass die tympanometrisch gemessene untere Grenze für normalen Mittelohrdruck zwischen -2 kPa und -1.5 kPa liegen soll.

Die passive Drucköffnungs- und Schliessungsfunktion der Ohrtrompete, die ihre Schliessungskraft und damit ihre schützende Funktion spiegelt, unterschied sich dagegen nicht bei Kindern und Erwachsenen; die Messung wurde bei standardisierter Druckänderungsgeschwindigkeit in einer Druckkammer durchgeführt.

Alle Erwachsenen konnten Luft durch die Ohrtrompete zum Mittelohr entweder durch Valsalva's Manöver oder durch die Mund-zur-Nase-Methode blasen. Die Kinder, denen dies nicht gelang, hatten signifikant niedrigeren Rhinopharynxdruck und höhere passive Drucköffnungs- und Schliessungsniveaus. Es zeigte sich, dass der Schliessungsdruck der Ohrtrompete, der ein Mass für die schliessende Fähigkeit der extraluminale Faktoren ist, eine relativ konstante und zuverlässige Variabel ist, die sich zu einer Wertung der Schutzfunktion der Ohrtrompete auch ohne Druckkammer eignet. Die Fähigkeit, durch eine Deflationsmanöver mit entweder offener (Schnüffelttest) oder geschlossener Nase (das umgekehrte Valsalvamanöver) Unterdruck im Mittelohr zu erzielen, stand teils mit der Drucköffnungs- und Schliessungsfunktion und teils mit dem durch diese Manöver bewirkten Unterdruck im Rhinopharynx in Beziehung. Ein positiver Schnüffelttest ist an sich nicht pathologisch, wenn der so erhaltene Unterdruck im Mittelohr mit einem guten aktiven Druckausgleich ausgeglichen werden kann. Dagegen kann möglicherweise die Kombination von Schnüffeln, geringem Schliessungsdruck und schlechter aktiver Druckausgleichsfähigkeit ein Mechanismus für die Entstehung eines bestehenden Unterdruckes im Mittelohr und damit zusammenhängender Krankheitszustände sein.

Eine Gruppe der Kinder, bei denen die Ohren gesund waren, zeigte eine Verschlechterung von sowohl der aktiven als auch der passiven druckausgleichenden Fähigkeit und niedrigeren Mittelohrdruck, als sie unter Erkältung untersucht wurden. Diese Veränderungen der Funktion der Ohrtrompete kann eine Erklärung für die hohe Frequenz von vorübergehendem Mittelohrunterdruck mit oder ohne Flüssigkeit sein. Bei vielen Kindern mit einer physiologischen Hypofunktion der Ohrtrompete auf Grund primärer schlechter muskulärer Öffnungsfähigkeit kann obere Luftwegsinfektion zu einem länger andauernden Zustand von Ohrenkatarrh beitragen.

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EUSTACHIAN TUBE FUNCTION IN NORMAL CHILDREN AND ADULTS

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Abstract. Eustachian tubal function was studied in 85 otologically healthy children, 3-12 years of age. Middle ear pressure and muscular opening function was measured by tympanometry performed in a pressure chamber, and the results were compared with those obtained from 92 normal adults. Children were found to have a less good muscular opening function and more negative middle ear pressures within wider ranges, compared with adults. Improvement was also seen in children with increasing age. The results seemed to indicate a relation between muscular opening function and middle ear pressure. Even if it were possible to grade the muscular opening function by means of the test procedure, it would still not be possible to define what should be regarded as normal or abnormal tubal function. This report is the first in a series of tubal function studies in normal children.

Middle ear disease is one of the most common pathologic conditions in childhood and despite lack of conclusive evidence, dysfunction of the tube has long been widely accepted as an important contributory cause of diseases of the middle ear.

In children the function of the Eustachian tube has mostly been assessed from the intratympanic pressure and screening by tympanometry has revealed a high incidence of negative middle ear pressure in children in both the absence and presence of subjective symptoms (Brooks, 1969; Harker & Wagoner, 1974; Fiellau-Nikolajsen et al., 1977; Renvall et al., 1978; Tos et al., 1978).

A negative intratympanic pressure has been regarded as a sign of impairment of tubal function, though opinions still differ as to the range of middle ear pressure that should be regarded as normal, and so far we do not know the clinical significance of a negative intratympanic pressure.

Also the pressure equilibration test, introduced by Flisberg et al. (1963), has been used for assessing tubal function in childhood and an association has often been found between middle ear diseases and Eustachian tube dysfunction (Silverstein et al., 1966; Westergaard, 1970; Bluestone et al., 1974; Cantekin et al., 1976; Poulsen & Tos, 1977; Spillman, 1977). However, this method can be used only if the tympanic membrane is perforated and can therefore not be applied in the examination of children with intact ear drums.

Corroboration and a rounded conception of the assumed relationship between Eustachian tube function and middle ear diseases in children requires first of all a knowledge of a variety of pertinent parameters of tubal function in children with normal ears. Such knowledge is hitherto scanty and there are only a few reports on single parameters of tubal function in children selected as normal (Brooks, 1968; Hopkinson, 1978).

As a link in the investigation of the problem we therefore decided to study two parameters, namely the intratympanic pressure and the ability of children to equilibrate, by muscular activity of the tube, experimentally induced over- and underpressure in the middle ear.

In the presentation of our results we decided to use the nomenclature proposed by Ingelstedt (1978). The basis of this standardization is (a) whether or not the tube opens by action of tubal muscles, and (b) the direction of air-flow through the tube. The pressure equilibration capacity by tubal muscular activity is called the *muscular opening function*. To de-

scribe in one word, the equilibration of a negative pressure in the middle ear by muscular activity, with an airflow from the nasopharynx to the middle ear, *inhalation* was suggested. *Exhalation* was suggested to express airflow from the middle ear to the nasopharynx, i.e. equilibration of overpressure in the middle ear, also by muscular opening of the tube.

Two main requirements have to be met when studying Eustachian tube function in normal children. The first is to find otologically healthy children, who in the present study were evaluated on the basis of their history, otoscopy or otomicroscopy including Siegle's pneumatic otoscope, tympanometry and hearing tests. The second is to find a non-traumatic, physiological method for evaluating the Eustachian tube function acceptable even for small children. Methods requiring a perforated eardrum could not be accepted as physiological, nor could children with eardrum perforations be classified as otologically healthy. Tympanometry is a non-traumatic, reliable and physiologic method for indirectly testing Eustachian tube function, since middle ear pressure can be assessed behind an intact eardrum (Brooks, 1969; Jerger, 1970). By means of a pressure chamber it is possible to induce over- and underpressure in the middle ear in a physiological way for testing the equilibration ability. Tympanometry in combination with a pressure chamber meets the second requirement. Thomsen (1958) introduced the acoustic impedance method in a pressure chamber in a similar way.

In the present study we also examined otologically healthy adults with the same method and for the following reasons: (1) we thought it would be of interest to compare the Eustachian tube function between children and adults since no such comparison has ever before been made and since it might be of value in the evaluation of the role of the Eustachian tube in middle ear disease in children: (2) by using the same performance as Elner et al. (1971), who used a more sophisticated non-traumatic method in their study of Eustachian

tube function in normal adults, it would be possible to test the reliability of our method.

This investigation concerns (1) the Eustachian tube function in otologically healthy children and comparison of the results with those obtained in normal adults tested by the same method and performance; (2) the relation between the intratympanic pressure and muscular opening function; (3) any differences related to age.

MATERIAL AND METHODS

The material consisted of 85 children, 44 girls and 41 boys, aged 3–12 years (mean 7.4 years) and 92 adults, 58 women and 34 men, aged 17–73 years (mean 31.8 years). The criteria to be met for a participant to be regarded as otologically healthy were: no history of recurrent otitis media acuta, no history of persistent or recurrent middle ear effusion or hearing trouble, no previous history of obstructing adenoid or allergy, no symptoms or signs of upper respiratory tract infection when tested, normal otomicroscopic or otoscopic findings including Siegle's pneumatic otoscope, pure tone hearing thresholds within 20 dB (ISO standard 1964) and V-shaped tympanograms (A or C according to Jerger, 1970) indicating air-filled middle ear spaces. Informed consent of the parents of the children was obtained before the test. Only data on children who cooperated satisfactorily throughout the investigation were included in the analysis of the findings. Most of the children were selected from nursery schools, families of colleagues, etc., and most of the adults from the staff of the ENT Clinic in Malmö.

Equipment

Fig. 1 shows an outline of the equipment. An electro-acoustic impedance bridge model ZO 70 (Madsen Electronics) with a probe frequency of 220 Hz was used for tympanometric recording of middle ear pressure and for recording of tubal openings indicated by

changes in the compliance curve. An external pressure transducer (EMT 33, Siemens Elema, Stockholm, Sweden) was connected to the system and used instead of the less sensitive internal pressure transducer of the bridge to minimize non-linear effects. The external pressure transducer had a pressure range of $\pm 408 \text{ mmHg}$ ($\sim \pm 4 \text{ kPa}$). A pressure chamber was used to induce static relative over- and underpressures in the middle ear. The chamber pressure was recorded with a pressure transducer (EMT 35 Siemens Elema, Stockholm, Sweden) with a maximal pressure range of $\pm 4080 \text{ mmHg}$ ($\sim \pm 40 \text{ kPa}$). The compliance curve, the ear canal pressure and the chamber pressure were synchronised and recorded on a multi-channel ink jet recorder (Mingograph 81 Siemens Elema, Stockholm, Sweden). The impedance bridge was calibrated according to the recommendations of the manufacturer. The ear canal pressure device and the chamber pressure were calibrated against an alcohol manometer before and after each examination.

Performance

With the subject seated comfortably in the pressure chamber, the test procedure was explained and instructions were given for the performance of the different tests. The small children needed an assistant in the chamber for instruction and entertainment. The probe was sealed air-tight in the ear canal by the examiner. The probes from Madsen Electronics were used, and no sealing problems arose except in two children, who had to be excluded. Most children tolerated the probes well. The equipment allowed only measurements of one ear at a time and, for practical reasons, only the left ear was tested. All recordings of the tests were performed by the same examiner.

The Eustachian tube function was assessed in the following two ways: (1) indirect measurement of the middle ear pressure by means of tympanometry which was performed before the equilibration test. Starting from ambient

pressure, the ear canal pressure was automatically changed by the air pump of the bridge at a speed of 20 mmHg/s (0.2 kPa/s), until the compliance peak was reached, whereafter the ear canal pressure was changed back again to the ambient pressure. The mean of the two compliance peaks on the ear canal pressure scale was calculated and regarded as the initial middle ear pressure. (2) The pressure equilibration capacity of the Eustachian tube, called the exhalation/inhalation capacity, was then quantitatively evaluated. At first a static relative overpressure of 100 mmHg (1 kPa) was created in the middle ear by changing the pressure in the chamber. The induced middle ear pressure was checked by tympanometry. An open communication between the ear canal and the chamber was established with the aid of a valve (Fig. 1) to equalize the pressure in the ear canal with that in the chamber. During tympanometry the valve was closed in order to make it possible to change the ear canal pressure alone. The subject was asked to equilibrate the tympanometrically controlled middle ear overpressure of 100 mmHg (1 kPa) by different equilibration methods. At first the subject was instructed to swallow 10 times, wet (juice) and dry alternatively within 3 minutes. If the middle ear pressure was not equilibrated completely with the chamber pressure by deglutition, as controlled by tympanometry, the subject was instructed to open the mouth, yawn, chew, move the mandible laterally, and swallow again repeatedly. This is called *the method of free choice*, and this part of the test was continued for up to 5–10 minutes. Any residual pressure in the middle ear was finally revealed by tympanometry. Neither Valsalva's manoeuvre nor any other method requiring the use of hand was allowed.

The procedure was repeated with a negative pressure of 100 mmHg (1 kPa) in the middle ear, created by the pressure chamber and the results of the inhalation capacity were then recorded.

The subjects were classified according to tubal function groups, as described by Elner

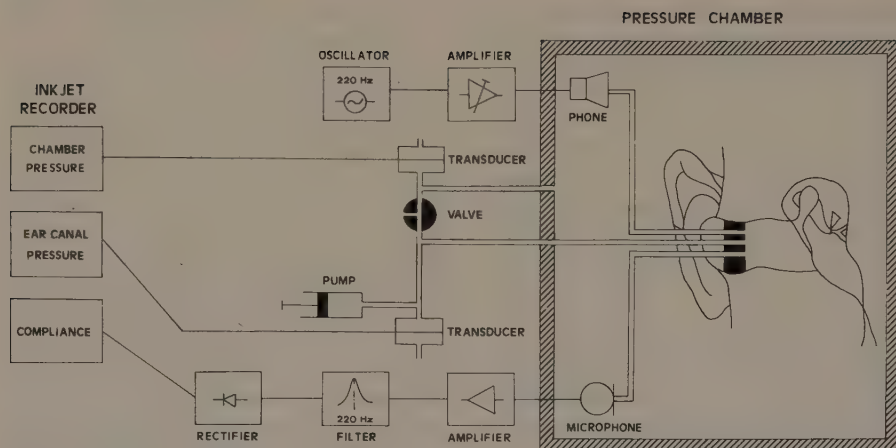


Fig. 1. A schematic illustration of the equipment.

et al. (1971). We decided to use this classification in order to allow a comparison of our results with theirs. Group I equilibrated both positive and negative pressures of 100 mmH₂O (1 kPa) completely (residual pressure 0–10 mmH₂O). Group II equilibrated partially positive and negative pressures (10–90 mmH₂O). Group III equilibrated positive pressures completely or partially, but not any applied negative pressure. Group IV equilibrated neither the positive nor the negative pressure of 100 mmH₂O (1 kPa) at all. Groups I and II are assumed to have good tubal function, as air-flow passes in both directions of the tube. Groups III and IV are assumed to reflect poor tubal function, as no equilibration of any negative pressure was recorded during the test period.

RESULTS

Equilibration by muscular opening of the tube—exhalation/inhalation test

Table I shows the results obtained when deglutition alone was allowed as the equilibration technique. The results are presented together with the figures given by Elner et al. (1971). As seen from the table, 61% of the children

(groups III and IV) could not equilibrate a relative underpressure in the middle ear of 100 mmH₂O (1 kPa), compared with 10% of the adults in our study and with 7% in the normal material of Elner et al. (1971).

When the subjects were allowed to equilibrate by the method of free choice, i.e. opening of the mouth, yawning, etc., 28 children (33%) and 14 adults (15%) were upgraded to a better tubal function group (Tables II and III). Table II shows that 29 children (34%) were unable to open the tube by deglutition alone (group IV) within the test period of 3

Table I. Distribution of 85 children and 92 adults among tubal function groups I–IV by deglutition alone, compared with the material of Elner et al. (1971)

Tubal function group	Children		Adults		Adults (accord. to Elner et al.)	
	n	%	n	%	n	%
I	24	28	68	75	74	72
II	9	11	14	15	21	21
III	23	27	6	7	2	2
IV	29	34	4	3	5	5
Total	85	100	92	100	102	100

Table II. Distribution of 85 children among tubal function groups I–IV in relation to different methods of equilibration

Equilibration method	Tubal function group ...	Method of free choice (10–20 min)				Total
		I	II	III	IV	
Deglutition (3 min)	I	24				24 (28 %)
	II	5	4			9 (11 %)
	III	7	2	14		23 (27 %)
	IV	6	1	7	15	29 (34 %)
	Total	42 (49 %)	7 (8 %)	21 (25 %)	15 (18 %)	85 (100 %)

min. However, when the children were allowed to use the equilibration method of free choice for up to 10–20 min, 14 of the 29 children in group IV were able to open the tubes and were upgraded to better groups. It is also clear from Table II that 6 children, who were completely unable to equilibrate by deglutition, improved from group IV to group I. This upgrading followed a single opening of the jaw. Two adults were upgraded from group IV to group I when using the method of free choice (Table III).

Although so many children improved by using the equilibration method of free choice, there was still a significant difference in the exhalation/inhalation capacity between children and adults ($p < 0.001$, χ^2 -test). Forty-three per cent of the children could not equilibrate any negative middle ear pressure (groups III and IV) compared with 4% of the adults (Fig. 2). Eighteen per cent of the children could not even equilibrate any positive pres-

sure (group IV) within the test period, i.e. they had no measurable equilibration capacity. None of the adults, however, belonged to the tubal function group IV when using the equilibration method of free choice. Two children and 2 adults had patulous tubes without symptoms. Their tubes could not withstand the pressure difference across the tube in the test situation. They were all assigned to group I. Fig. 3 demonstrates that the younger children had a poorer equilibration capacity than the older ones. This is also clear from Table IV, in which 74% of the children of 3–5 years of age had a poor tubal function (groups III and IV), compared with 34% of the children of 6–8 years of age and 27% of the children of 9–12 years of age ($p < 0.001$, χ^2 -test). The frequency of good function (groups I and II) and of poor function (groups III and IV) did not vary with sex in any age group or in the entire material of 44 girls and 41 boys ($p > 0.05$, χ^2 -test and Fisher's exact test).

Table III. Distribution of 92 adults among tubal function groups I–IV in relation to different methods of equilibration

Equilibration method	Tubal function group ...	Method of free choice (10–20 min)				Total
		I	II	III	IV	
Deglutition (3 min)	I	69				69 (75 %)
	II	8	6			14 (15 %)
	III		3	3		6 (7 %)
	IV	2		1		3 (3 %)
	Total	79 (86 %)	9 (10 %)	4 (4 %)	0	92 (100 %)

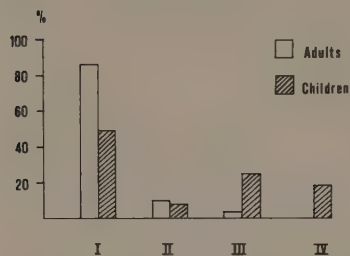


Fig. 2. Distribution of 85 children and 92 adults among tubal function groups I-IV, by equilibration method of free choice.

Middle ear pressure

The initial middle ear pressure recorded before the exhalation/inhalation test showed more negative values and within a wider range in the children ($Pm_{\text{mean}} = -29.5 \text{ mmH}_2\text{O}$, range $+80$ to $-200 \text{ mmH}_2\text{O}$) than in the adults ($Pm_{\text{mean}} = -4.2 \text{ mmH}_2\text{O}$, range $+30$ to $-80 \text{ mmH}_2\text{O}$). There was a significant difference in distribution of middle ear pressure between the children and the adults ($p < 0.001$, χ^2 -test). Fig. 4 shows that in the children as well as in the adults the mean intratympanic under-

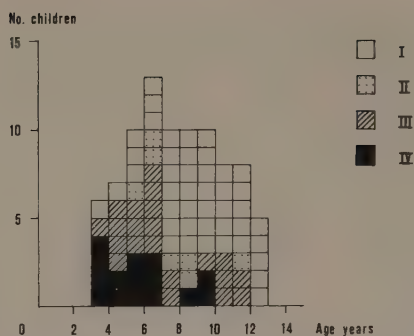


Fig. 3. Age distribution of 85 children, assigned to tubal function groups I-IV by equilibration method of free choice.

pressure was greater in poorer tubal function groups (groups III and IV). Fig. 5 gives a schematic presentation of the distribution of the initial middle ear pressure in relation to tubal function groups in the children and the adults. As seen from this figure, 13 children (10–26 % with 95 % confidence)—by definition regarded as otologically healthy—had an intratympanic pressure equal to or more negative than $100 \text{ mmH}_2\text{O}$ (1 kPa). Ten of these 13

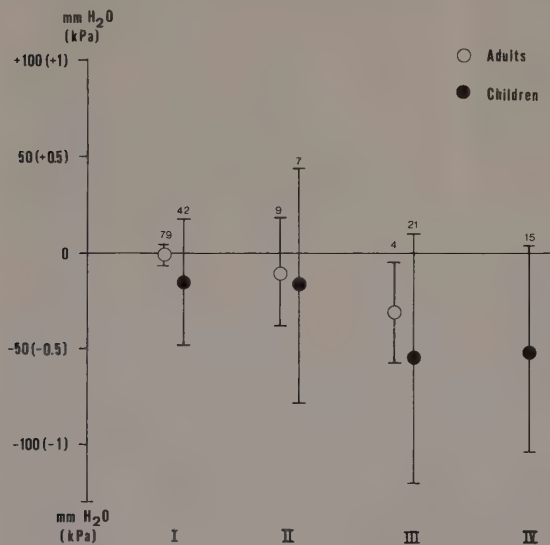


Fig. 4. Initial middle ear pressure (Mean $\pm$ S.D.) in 85 children and 92 adults, distributed among tubal function groups I-IV, by equilibration method of free choice. Figures over S.D. denote number of subjects.

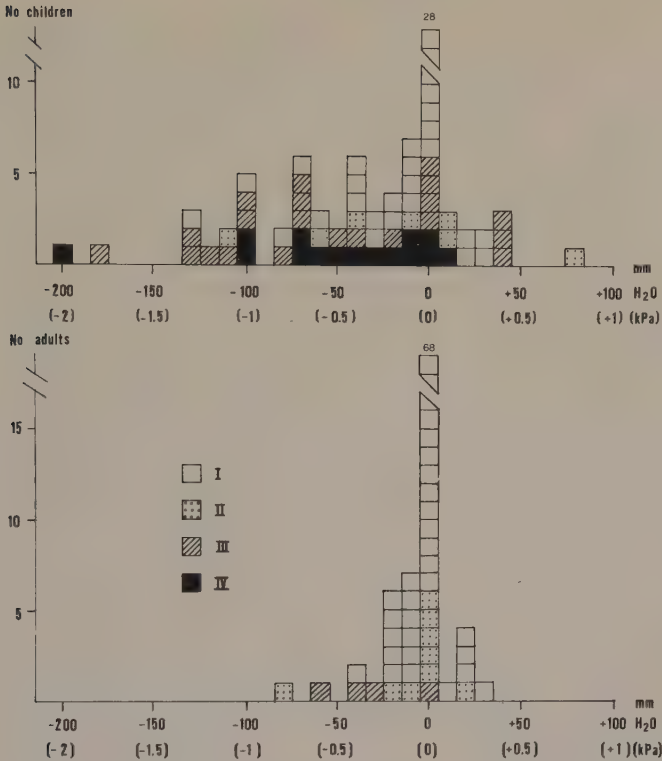


Fig. 5. Distribution of 85 children and 92 adults according to initial middle ear pressure. The figure also gives the tubal function groups I-IV of each subject, by equilibration method of free choice, in relation to initial middle ear pressure.

children were assigned to the poor tubal function groups III and IV, while 3 could equilibrate the initial middle ear underpressure (groups I and II) indicating good tubal function. On the other hand, 9 children had an

initial middle ear pressure close to that of the ambient pressure ($P_m \pm 10 \text{ mmH}_2\text{O}$) (0.1 kPa) in spite of the fact that they were classified as having no inhalation function (groups III and IV).

The mean initial middle ear pressure in the youngest children (3-5 years of age) was significantly more negative ($p < 0.05$, Student's *t*-test) than in the oldest ones (9-12 years of age), which is in accordance with the finding of poorer exhalation/inhalation capacity in the younger children (Table IV).

Table IV. Distribution of 85 children in different age groups among tubal function groups I-IV

Tubal function group	3-5 years		6-8 years		9-12 years	
	n	%	n	%	n	%
I	5	22	16	50	21	70
II	1	4	5	16	1	3
III	8	35	7	22	6	20
IV	9	39	4	12	2	7
Total	23	100	32	100	30	100

DISCUSSION

The exhalation/inhalation test clearly demonstrates that normal children have a less good

muscular opening function than normal adults. Sixty-one per cent of the children could not equilibrate applied negative pressures by deglutition, compared with 10% of the adults. Elner *et al.* (1971) reported that 7% of their normal adults could not equilibrate negative intratympanic pressures. They used a very sophisticated recording method, and since their results in normal adults are in good agreement with ours, we think this supports the reliability of our method.

The subjects examined in the present study were all apparently otologically healthy. Yet, more than half of the children had a poor muscular opening function (groups III and IV).

In an attempt to adapt the exhalation/inhalation test to meet more physiological demands the test was extended to allow not only voluntary swallowing but also different jaw movements, *i.e.* the equilibration method of free choice, and this part of the test was continued for up to 10–20 min.

When using this equilibration method, one-third (33%) of the children and one-seventh (15%) of the adults improved their results. Six (14%) children were upgraded from the poorest (group IV) to the best (group I) by a single movement of the jaw. Thus, deglutition did not open the tubes in these 6 cases, whereas a single jaw movement revealed their perfect muscular opening function. This is of interest, since some authors have observed that deglutition may be ineffective or that in some subjects the tubal muscles might even constrict the Eustachian tube by deglutition (Jonas *et al.*, 1978; Beery *et al.*, 1980; Jauman *et al.*, 1980). Since one-third of the children could equilibrate more easily by the method of free choice it seems of importance to allow not only deglutition, but also different jaw movements, when testing the muscular opening function in children.

The prolonged test period would seem to permit recording of voluntary as well as involuntary opening of the tube. Perlman (1951) demonstrated that the tube does not always open on deglutition and suggested that in-

voluntary deglutition may be more effective than voluntary. In a few of the subjects, who improved their results, we also suspect that deglutition, opening the tube, was involuntary. For ethical and also practical reasons, however, we could not extend the testing time any longer to find out whether involuntary deglutition is more effective than voluntary.

Despite the use of the equilibration method of free choice together with the prolonged test period the results still show that the muscular opening function in normal children is significantly poorer than in normal adults. Forty-three per cent of the children could not equilibrate any underpressure, compared with 4% of the adults. Fifteen (18%) children could not even equilibrate any positive pressure applied, and thus had no muscular opening function, as judged with our method. All the adults could equilibrate overpressures with the method of free choice.

The muscular opening function was also shown to vary with age. The function was significantly poorer in younger children (3–5 years of age) than in older ones (6–8 years of age). The function found in the 9–12-year-old children was even better than in the younger groups, but still not so good as in the adults. This is a very interesting observation, since it is more or less generally accepted that Eustachian tube function improves with age. However, conclusive evidence has hitherto been lacking.

The mean of the middle ear pressures recorded by tympanometry before the exhalation/inhalation test was more negative and showed a wider range of variation in the children than in the adults. The mean middle ear pressure was also more negative in the younger children (3–5 years of age) than in the older ones (9–12 years of age). Similar results have been reported by Brooks (1969) and Jerger (1970). Thus, not only the muscular opening function but also the middle ear pressure was found to vary with age.

The present results showed an improved Eustachian tube function with increasing age.

This might be explained by anatomical differences of the tube in different age groups (Proctor, 1967; Holborow, 1970, 1975). Holborow concluded, from sections of the Eustachian tube in children of various ages and from functional studies, that the critical period of tubal insufficiency is relatively short, extending from birth to about 7 years of age. Jonas et al. (1978) and Mann et al. (1979) found that anatomical differences in the skull base were important for tubal function in children. Another possible explanation of the poor muscular opening function in children might be an insufficient neuro-muscular control of tubal opening muscles as a consequence of the low age. This is suggested to cause a lower frequency of tubal opening and also possibly another equilibration pattern and might further explain the variability of middle ear pressure in normal children.

The finding of poor tubal function in otologically healthy children, might, of course, be due to the difficulty in selecting normal children because of the well-known high incidence of middle ear disease in these groups. It is also almost impossible to exclude children with existing or very recent subclinical upper respiratory tract infections.

The clinical significance of negative middle ear pressure has been the subject of much discussion over the last decade. Several investigators have tried to differentiate between normal and abnormal middle ear pressures and the suggested limits have varied between $-25 \text{ mmH}_2\text{O}$ and $-250 \text{ mmH}_2\text{O}$ (-0.25 and -2.5 kPa) (Brooks, 1969; Bluestone et al., 1974; Harker & Wagoner, 1974; Holmqvist, 1974; Harford et al., 1978; Renvall et al., 1978; Lildholdt, 1980). The present study reports negative middle ear pressures of more than or equal to $100 \text{ mmH}_2\text{O}$ (1 kPa) in 13 children (10–26% with 95% confidence), who were regarded as otologically healthy. However, we could not demonstrate negative middle ear pressures of more than $200 \text{ mmH}_2\text{O}$ (2.0 kPa) in our material, which seems to support recent reports in which $-200 \text{ mmH}_2\text{O}$ has

been suggested as the level distinguishing normal from abnormal pressures (Harford et al., 1978).

There seems to be a relation between middle ear pressure and muscular opening function in the material as a whole (Fig. 4). This observation supports the assumption that a negative initial middle ear pressure indicates poor tubal function (Brooks, 1969; Bluestone et al., 1974; Harker & Wagoner, 1974; Renvall, 1975). On the contrary, in individual subjects we found several exceptions; 6 children with an initial middle ear pressure close to the ambient pressure despite no measurable muscular opening function, and another 3 children with a negative middle ear pressure of more than or equal to $100 \text{ mmH}_2\text{O}$ (1 kPa) but classified as having good muscular opening function. This might perhaps be due to the fact that a single measurement of middle ear pressure gives only a momentary picture and does not reflect the mean function of the tube. This has been shown by Lewis et al. (1975) and Schwartz et al. (1978) who documented a day to day fluctuation in middle ear pressure in children, and by Lildholdt (1980) who found a wide seasonal variation. Thus, when assessing tubal function by tympanometry, repeated measurements must be made.

Judging from our results, it seems possible to grade the muscular opening function by means of the exhalation/inhalation test. We suggest, however, that poor tubal function, as evaluated by the present method, should not be equated with 'pathological' tubal function.

On the other hand, the results also indicate that neither the exhalation/inhalation test nor any single recording of the middle ear pressure would make it possible to define what should be regarded as normal or abnormal tubal function. There are, however, several other parameters of the Eustachian tube function, which may be of importance in the etiology of middle ear disease in children and which need to be studied and related to each other before any conclusions regarding the role of the Eu-

stachian tube can be made. Such studies are in progress.

ZUSAMMENFASSUNG

Die Funktion der Ohrtrumpete wurde an 85 ohrengesunden Kindern zwischen 3 und 12 Jahren untersucht. Der Mittelohrdruck und die Druckausgleichfähigkeit (die muskuläre Öffnungsfunktion der Tube) wurden mit Tympanometrie in einer Druckkammer gemessen, und die Resultate wurden mit denen von 92 ohrengesunden Erwachsenen verglichen. Kinder wiesen eine schlechtere Tubenfunktion und größere Unterdrücke im Mittelohr mit größeren Abweichungen im Vergleich zu Erwachsenen auf. Mit steigendem Alter der Kinder wurde eine Verbesserung beobachtet. Die Resultate deuten darauf, daß der Mittelohrdruck und die muskuläre Öffnungsfunktion voneinander abhängig sind. Auch wenn es möglich war, die muskuläre Öffnungsfunktion der Tube mit Hilfe der Prüfverfahren abzustufen, gelang es doch nicht im Einzelfall, die normale von pathologischer Tubenfunktion zu unterscheiden. Diese ist die erste Mitteilung in einer Reihe von Studien über die Funktion der Ohrtrumpete bei normalen Kindern.

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PRESSURE OPENING AND CLOSING FUNCTIONS OF THE EUSTACHIAN TUBE IN CHILDREN AND ADULTS WITH NORMAL EARS

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Abstract. Eustachian tube function was studied with the impedance technique and a pressure chamber in 58 children, aged 3–12 years, and 61 adults, aged 17–73 years, all otologically healthy. The pressure opening and closing functions were measured, i.e. the relative overpressure in the middle ear required to force open the tube, and the residual overpressure in the middle ear after pressure opening, respectively. These “passive” functions of the tube, assumed to reflect the closing factors, did not differ significantly between normal children and adults. The muscular opening function, i.e. “active” pressure equilibration capacity, on the other hand, was significantly poorer in children than in adults and poorer in younger children than in older ones. The results can be used as a reference material in investigations of the Eustachian tube in children with middle ear disease.

In the last few decades interest has focused mainly on the muscular opening function of the Eustachian tube, but recent reports have stressed the importance of investigation of the pressure opening and closing functions of the tube as well (Bluestone et al., 1972, 1974; Cantekin et al., 1976; Ekvall & Magnusson, 1977; Ingelstedt, 1978; Magnusson, 1980).

Bluestone et al. (1972, 1974) and Cantekin et al. (1976) have tried to elucidate the nature of tubal dysfunction in children with middle ear effusions or recurrent otitis media. They often found poor muscular opening function in association with low opening pressures and suggested that functional obstruction of the tube, i.e. too distensible or compliant a tube, rather than mechanical obstruction, might be a causative factor of middle ear disease in children.

Ekvall & Magnusson (1977) and Magnusson (1980) reported impaired closing ability of the tube in chronic adhesive otitis media and retraction cholesteatoma. They proposed that

these patients with “closing failure”, i.e. low closing pressures of the tube, might get negative middle ear pressures due to habitual sniffing, which also in children might be an important factor for the retraction of the eardrum.

Before any conclusions can be drawn regarding the role of tubal dysfunction as an etiological factor in middle ear disease, it is obvious that knowledge must be acquired of tubal function in otologically healthy children and adults. It also seems important to investigate the pressure opening and closing functions as well as the muscular opening function of the tube.

Such an investigation requires a method, allowing the study of the above-mentioned variables of tubal pressure equilibration functions, in subjects with intact eardrums without disturbing the normal physiology of the middle ear. The impedance method in combination with a pressure chamber meets these requirements and has proved to be suitable also in the examination of small children (Bylander et al., 1981).

The aims of this study were: 1) to investigate the “passive” pressure opening and closing functions as well as the “active” muscular opening function in otologically healthy children of different ages; 2) to compare the results with those of normal adults tested with the same method; and 3) to compare the results of the “passive” functions with those of the “active” muscular opening function in these children and adults.

MATERIAL AND METHODS

The material consisted of 58 otologically healthy children, aged 3–12 years (mean 7.0 years) and 61 adults, aged 17–73 years (mean 29.8 years). The criteria for acceptance as otologically healthy were: no history of recurrent otitis media; no history of middle ear effusion or impairment of hearing; no history of obstructing adenoid or allergy; no symptoms or signs of upper respiratory tract infection when tested; normal otoscopic or otomicroscopic findings including examination with Siegle's pneumatic otoscope; pure tone hearing threshold within 0–20 dB (ISO standard 1964); and V-shaped tympanograms indicating air-filled middle ears.

Equipment

An electroacoustic impedance bridge, model ZO 70 (Madsen Electronics, Copenhagen, Denmark), with a probe frequency of 220 Hz was used for the recordings. A pressure chamber was used to induce static relative over- and underpressures in the middle ear for testing muscular opening function and to induce dynamic relative pressure changes in the middle ear for testing pressure opening and closing functions. The pressure range of the chamber was ± 7 kPa and the mean rate of pressure change from ambient pressure to -7 kPa was 0.37 kPa/s. During changes in chamber pressure an open communication between the ear canal and the chamber was established by a valve. The recordings were made on a multi-channel ink jet recorder (Mingograph 81, Siemens Elema, Stockholm, Sweden) with a chart speed of 10 mm/s. For further details of the equipment, see Bylander et al. (1981).

Performance

Informed consent of the children's parents was obtained before the tests. The subject was seated comfortably in the pressure chamber and instructions were given for the different tests. The small children needed an assistant in the chamber for instructions and entertain-

ment. Only the left ear of each subject was tested. All recordings of the tests were performed by one and the same examiner. Three variables of Eustachian tube function were studied, viz. muscular opening function, pressure opening function, and pressure closing function.

Muscular opening function was assessed from the subject's ability to equilibrate a static relative overpressure as well as a relative underpressure of 1 kPa in the middle ear, induced by changing the chamber pressure. The "active" pressure equilibration performed by the subject was standardized in the following way: if the middle ear pressure was not equilibrated completely by deglutition, wet (juice) and dry, alternately, 10 times within 3 min., the subject was instructed to open the mouth, yawn, move the mandible laterally and swallow repeatedly, for up to 10–20 min. This is called "the method of free choice", as described by Bylander et al. (1981). The subjects were divided into four tubal function groups according to Elner et al. (1971). Group I equilibrated both positive and negative pressures of 1 kPa to less than 0.1 kPa residual pressure. Group II equilibrated partially positive and negative pressures (residual pressures 0.1–0.9 kPa). Group III equilibrated positive pressures of 1 kPa completely or partially but not any applied negative pressures. Group IV equilibrated neither positive nor negative pressures of 1 kPa. Muscular opening function was assumed to be good in groups I and II as air passed in both directions in the tube, but to be poor in groups III and IV as no equilibration of negative pressure was recorded during the test period. The muscular opening function test has been described in detail elsewhere (Bylander et al., 1981).

Pressure opening function was assessed during decreasing pressure in the chamber by measuring the change in chamber pressure required to induce a relative overpressure in the middle ear necessary to open the tube (Fig. 1). This pressure change is called the pressure opening level (Pol). First the neutral position

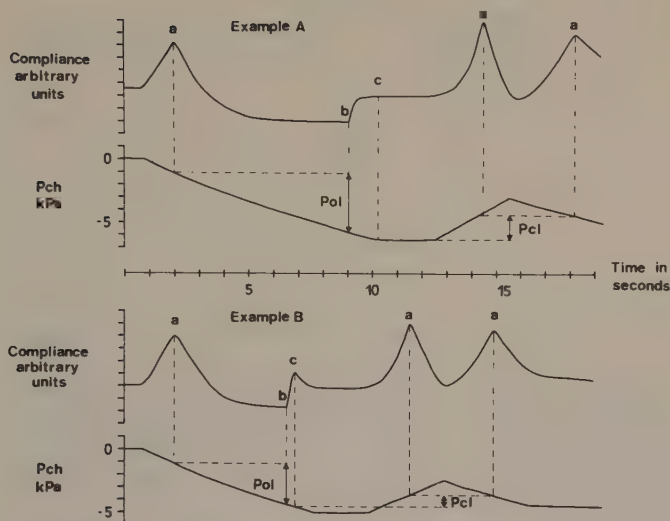


Fig. 1. Examples of recordings of compliance and chamber pressure (P_{ch}) with calculation of pressure opening levels (Pol) and pressure closing level (Pcl). (a) denotes the neutral positions of the eardrum = relative zero pressures in middle ear; (b) moment of pressure opening; and

(c) pressure closing of tube. In example A, after pressure opening, middle ear pressure was constant, i.e. the tube was continuously leaking, and in example B the tube opened and closed intermittently during chamber pressure decrease.

of the eardrum was determined from the compliance curve, indicated by the point of maximum compliance. This relative zero pressure level in the middle ear was then calculated from the chamber pressure curve (P_{ch}). The moment when the tube was forced open was clearly indicated by the sudden change in compliance caused by escape of air through the tube. The magnitude of Pol was thereafter calculated from the P_{ch} curve. The subject was told to avoid equilibration by muscular opening during the recording.

Pressure closing function expressed as the pressure closing level (Pcl) is by definition the residual overpressure in the middle ear when the tube is closed after pressure opening. During changes in chamber pressure, principally two different patterns of the tubal closing function were seen. In most subjects the tube worked as a constant pressure regulator after the pressure drop at pressure opening. This

means that air was continuously leaking from the middle ear during the decrease in chamber pressure (Fig. 1, example A). In other subjects the tube closed almost immediately after the pressure opening which is indicated by a pressure increase in the middle ear during further decrease in chamber pressure (Fig. 1, example B). If this increase in pressure in the middle ear continues, another pressure opening will occur. Thus, the tube worked as a pressure regulator by intermittent opening and closing. In a few cases not only one but repeated opening and closing of the tube occurred before it was possible to stop the pressure decrease in the chamber. In those few cases, the first pressure opening and the last closing of the tube was used for calculation of Pol and Pcl , respectively.

With tympanometry the neutral position of the eardrum, i.e. the relative zero pressure level in the middle ear, was identified by the

Table 1. Distribution of 58 children and 61 adults in relation to muscular opening function (tubal function groups I–IV) by equilibration method of free choice

The children are also distributed among the different age groups

Tubal function group	Children					Adults	
	3–5 years <i>n</i>	6–8 years <i>n</i>	9–12 years <i>n</i>	Total <i>n</i>	%	Total <i>n</i>	%
Tuba aperta							
I	2	15	1	1	2	52	84
II	2	5	—	7	12	6	11
III	6	4	3	13	22	3	5
IV	8	1	—	9	16	—	—
Total	18	25	15	58	100	61	100

mean of two maximum compliance peaks, and the magnitude of P_{cl} was then calculated from the P_{ch} curve as shown in Fig. 1, examples A and B. The subject was told to avoid equilibration by muscular opening during the recording.

RESULTS

Muscular opening function

Muscular opening function was significantly poorer in the children than in the adults ($p < 0.001$, χ^2 -test). As many as 38% of the children could not equilibrate a relative underpressure of 1 kPa (groups III and IV) by the method of free choice compared with 5% of the adults (Table I). The table also shows that the muscular opening function varied with the children's ages. Fourteen (78%) out of 18 children, 3–5 years old, could not equilibrate any underpressures (groups III and IV), compared with 5 (20%) out of 25 children, 6–8 years old, and 3 (20%) out of 15 children, 9–12 years old. The improvement with age was statistically significant ($p < 0.001$, χ^2 -test).

Comments. One 9-year-old girl had tuba aperta without symptoms, even in the recumbent position. Neither the results of the muscular opening function test nor those of the pressure opening and closing function tests could therefore be recorded. In 3 adults the tubes could not withstand the small pressure differences of ± 1 kPa in the muscular opening function test. However, the pressure opening

function could be recorded, which may be explained by a faster pressure change in this test. These adults were all traditionally assigned to tubal function group I, according to Elner et al. (1971).

Pressure opening function

In the children the mean Pol was 3.86 kPa (SD ± 1.08 kPa, range 1.18–5.78 kPa) and in the adults 4.19 kPa (SD ± 1.53 kPa, range 1.37–8.04 kPa). There was no significant difference between the two groups (Student's *t*-test. The test was approximated as the variances differed between the groups.)

The mean Pol is given in relation to the muscular opening function in Table II. In the children there were no significant differences in the mean Pol between the tubal function groups I–IV (analysis of variance). In the adults, however, there was a tendency to such differences ($p < 0.05$, analysis of variance). Further analysis of the differences among the adults (Scheffe's method for simultaneous confidence intervals) revealed that in group III the mean Pol was significantly higher than that in group I. The findings must, however, be interpreted with caution as group III was small. Furthermore, there were no significant differences in the mean Pol between the different age groups (3–5, 6–8, 9–12 years old) of the children (analysis of variance) (Table IV).

Comments. The Pol was measurable in 55 out of 58 children and in 60 out of 61 adults.

Table II. Pressure opening function (Pol) in kPa (mean and $\pm$ SD) in relation to muscular opening function (tubal function groups I–IV) in children and adults with normal ears

Tubal function group	Children			Pol (kPa)	Adults		
	n	Mean	SD		n	Mean	SD
I	27	3.58	± 1.26		52	4.04	± 1.49
II	7	4.12	± 0.72		5	4.68	± 1.24
III	13	4.07	± 0.77		3	5.88	± 1.89
IV	8	4.26	± 0.96		—	—	—
Total	55	3.86	± 1.08		60	4.19	± 1.53

For obvious reasons the girl with tuba aperta was excluded. Another child and one adult showed no distinct Pol, probably due to continuously leaking tubes, and in a third child the Pol was not reached owing to the limited pressure range of the chamber.

Pressure closing function

The mean Pcl was 1.17 kPa (SD ± 0.72 kPa, range 0.20–3.53 kPa) in the children and 1.32 kPa (SD ± 0.89 kPa, range 0–3.72 kPa) in the adults. There was no significant difference between the two groups (Student's *t*-test). The relation between the mean Pcl and the muscular opening function is given in Table III. In the adults there were no significant differences in the mean Pcl between the tubal function groups I–IV (analysis of variance). However, in the children, the differences were significant ($p < 0.01$, analysis of variance). These differences between tubal function groups in the children were analysed further with Scheffe's method for simultaneous confidence intervals and showed a higher mean Pcl in the poorer

tubal function groups III and IV than in group I.

Table IV gives the mean Pcl for the different age groups of the children. The mean Pcl tended to be higher in the two youngest groups than in the oldest one, but analysis of variance showed no significant difference. Fig. 2 shows the relation between the mean Pol and the mean Pcl for both children and adults in relation to tubal function groups.

Comments. The Pcl could be measured in 54 out of 58 children and in 56 out of 61 adults. The remainder were excluded for the same reasons as in the Pol test or because of leaking tubes even after reduction of the chamber pressure was finished, which means that no accurate Pcl by definition could be estimated.

Thirty-two children and 46 adults showed compliance curves after pressure opening, as demonstrated in Fig. 1, example A. In 10 adults and 22 children the tube opened and closed intermittently, once or repeatedly (Fig. 1, example B). In children and adults both Pol and Pcl were significantly lower in the record-

Table III. Pressure closing function (Pcl) in kPa (mean and $\pm$ SD) in relation to muscular opening function (tubal function groups I–IV) in children and adults with normal ears

Tubal function group	Children			Pcl (kPa)	Adults		
	n	Mean	SD		n	Mean	SD
I	26	0.89	± 0.56		47	1.17	± 0.81
II	6	1.13	± 0.63		6	1.94	± 1.10
III	13	1.21	± 0.45		3	2.29	± 0.63
IV	9	1.97	± 0.96		—	—	—
Total	54	1.17	± 0.72		56	1.32	± 0.89

Table IV. Age distribution of pressure opening and closing functions (Pol and Pcl) in kPa (mean and $\pm$ SD) in children with normal ears

Children (age groups in years)	Pol (kPa)			Pcl (kPa)		
	n	Mean	SD	n	Mean	SD
3-5	17	3.75	± 1.07	18	1.28	± 0.86
6-8	24	3.97	± 1.12	23	1.31	± 0.67
9-12	14	3.81	± 1.06	13	0.77	± 0.45
Total	55	3.86	± 1.08	54	1.17	± 0.72

ings in example B than in those in example A ($p < 0.001$, Student's *t*-test).

The difference between Pol and Pcl, which is thought to reflect the intraluminal closing forces of the tube, was 2.71 kPa (SD ± 0.77 kPa) in the children and 2.95 kPa (SD ± 1.00 kPa) in the adults. There was no significant difference between the two groups (Student's *t*-test). Neither was there any significant difference in this variable between different tubal function groups or between different age groups of the children (analysis of variance).

Reliability of pressure opening and closing levels

The reliability of measurements of Pol and Pcl with the method described was calculated in 40 adults and 12 children, including both types of compliance curve from two or three recordings in the same test situation. The standard deviation of repeated measurements, i.e. the total error of the method for Pol was ± 0.22 kPa in the adults and ± 0.17 kPa in the children. The corresponding values for Pcl were ± 0.15 kPa and ± 0.25 kPa, respectively.

DISCUSSION

Middle ear disease is generally related to functional impairment of the Eustachian tube, but convincing evidence of the dysfunction being a primary etiologic factor is still lacking. Such impairment might equally well be secondary to the disease itself. Since middle ear disease is so common in childhood, it was thought worth while to try to find out whether and to what

extent the Eustachian tube function in childhood differs from that in adult age. Thus, it is first of all necessary to study the tubal function in otologically healthy children and to compare the results with those in healthy adults. The results of such an investigation could then be used as a reference material in the discussion regarding the relation between tubal dysfunction and middle ear disease.

The results showed that muscular opening function, i.e. the active pressure equilibration capacity, was less good in normal children than in normal adults and that the function was much poorer in younger children (3-5 years

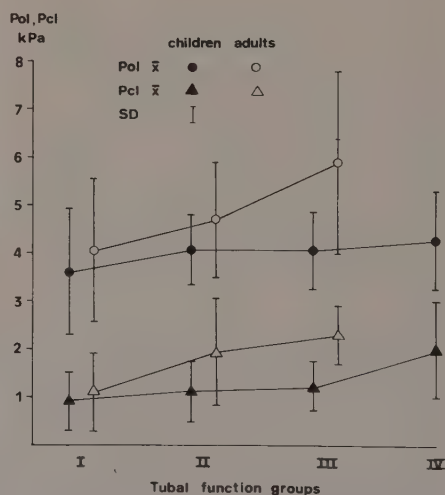


Fig. 2. Pol and Pcl (mean and $\pm$ SD) in different tubal function groups (I-IV). Comparison between normal children and adults.

old) than in older ones (6–12 years old), as also shown in an earlier study (Bylander et al., 1981).

However, normal children did not differ from adults as regards pressure opening function (Pol) or pressure closing function (Pcl). Neither did these functions vary with the children's ages. The impedance technique in combination with a pressure chamber proved to give reproducible results, as demonstrated by the results obtained on repeated measurement. The similar results of Pol in otologically healthy adults, reported by other authors (Elner et al., 1971; Tjernström, 1974; Groth et al., 1980) who used the more sophisticated microflow method and a pressure chamber, also confirm the reliability of the method used in the present study.

When recording Pol and Pcl it was seen that the middle ear pressure was principally regulated in two different ways during decreasing chamber pressure. In most ears (71%) the middle ear pressure remained constant after the pressure opening of the tube despite the continuous decrease in chamber pressure. In these cases the tube worked as a constant pressure regulator by continuous leakage. In the other ears (29%) the tube closed almost immediately after the pressure opening and, owing to the chamber pressure decrease, the middle ear pressure again increased until the next pressure opening eventually occurred. Such intermittent opening and closing was seen once or repeatedly, depending on the duration of the pressure decrease in the chamber.

The mean Pol and the mean Pcl were significantly lower in the ears with intermittent opening and closing of the tube than in those where the middle ear pressure remained constant. It should also be observed that this pattern was more common in children (40%) than in adults (18%). Yet the Pol and Pcl did not differ between children and adults in the material as a whole. Elner et al. (1971) also described the two different patterns of middle ear pressure regulation but excluded those ears with intermittent opening and closing when calculating

Pcl. This may explain the differences between his Pcl (mean 1.79 kPa) and ours (mean 1.32 kPa) in normal adults. The rate of pressure change in the middle ear seems to influence the frequency of the two patterns of middle ear pressure regulation (Cantekin et al., 1979), but cannot explain the difference in distribution in children and adults as demonstrated in the present study.

The differences in the muscular opening function between normal children and adults and also between children of different ages might reflect an immature neuromuscular function which improves with age. According to Holborow (1970, 1975) the tubal and peritubal anatomy changes throughout childhood, which also may influence the efficiency of the tubal muscular mechanics.

The pressure opening function is thought to reflect the total closing forces of the tube, including both luminal and extraluminal factors (Zöllner, 1942; Perlman, 1967; Bluestone et al., 1974; Ingelstedt, 1978). The pressure closing function is believed to comprise extraluminal factors, including the elasticity of both the tubal cartilage and other peritubal structures, such as muscles, ligaments and vessels, and the hydrostatic peritubal pressure (Ingelstedt, 1978; Cantekin et al., 1979). Perlman (1939) and Guindi & Charia (1980) assume that the tonus of tubal muscles also plays a part in the closing mechanism. Thus, according to reported differences in tubal and peritubal anatomy between children and adults (Aschan, 1954) and also between children of different ages (Holborow, 1970), one would have expected differences in Pol and Pcl between children and adults.

The difference between the total closing factors and the extraluminal factors (Pol minus Pcl) is assumed to reflect the luminal components of the total closing forces. These luminal (mucosal) factors, representing the viscosity of secretion, surface tension of the mucus, and the blood content and elasticity of the mucosal vessels (Cantekin et al., 1976; Ingelstedt, 1978), were fairly constant in the normal sub-

jects, and the statistical analysis showed no difference between the two groups.

In the present study there seemed to be a slight relation between the muscular opening function and high Pol and Pcl for both children and adults, but the relation was significant only for Pcl in the children (Fig. 2).

Our results in normal children differ from those in children with middle ear disease, investigated with perforated eardrums (Bluestone et al., 1972, 1974; Cantekin et al., 1976; Magnusson, 1980). They assumed children with middle ear disease to have a functional obstruction or a general closing failure of the tube. Our findings in normal children with poor muscular opening function rather support the assumption of a mechanical obstruction of the tube, since Pcl increased with decreasing muscular opening function. However, the significance of these different results cannot be evaluated until wholly comparable studies have been performed.

ZUSAMMENFASSUNG

Die Funktion der Ohrtrompete wurde mit Impedanztechnik und Druckkammer an 58 Kindern im Alter von 3–12 Jahren und 61 Erwachsenen im Alter von 17–73 Jahren untersucht, die alle otologisch gesund waren. Die Drucköffnungsfunktion ist als relativer Überdruck im Mittelohr zu verstehen, der notwendig ist, um die Tuba zu öffnen. Die Druckschließfunktion ist als residualer Überdruck im Mittelohr nach der Drucköffnung aufzufassen. Diese „passiven“ Funktionen der Tuba, von denen angenommen wurde, daß sie die Schließfaktoren sind, haben sich bei Kindern und Erwachsenen nicht signifikant unterschieden. Andererseits war die muskuläre Öffnungsfunktion, d. h. die „aktive“ Druckausgleichsfähigkeit, bei Kindern signifikant schlechter als bei Erwachsenen, und bei jüngeren Kindern schlechter als bei älteren. Die Resultate können als Referenzmaterial für Untersuchungen von der Ohrtrompete bei Kindern mit Mittelohrerkrankungen angewendet werden.

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PRESSURE OPENING AND CLOSING FUNCTIONS OF THE EUSTACHIAN TUBE BY INFLATION AND DEFLATION IN CHILDREN AND ADULTS WITH NORMAL EARS

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Abstract. Different inflationary (e.g. Valsalva's) and deflationary (e.g. sniffing) manoeuvres were studied in 58 children and 61 adults, all otologically healthy, in order to evaluate qualitatively and quantitatively the pressure opening and closing functions of the Eustachian tube. Only 71% of the normal children could voluntarily increase the middle ear pressure compared with 100% of the adults. The corresponding figures for evacuating the middle ear by deflation were 24% and 34%, respectively. The rhinopharyngeal pressure levels during the manoeuvres were age-dependent and decided the response rate in children. Tubal factors also determined the response rate since low pressure opening and closing levels were related to successful deflation. Negative middle ear pressures found in the normal children were due to poor muscular opening function of the tube rather than successful deflation. The pressure closing level seems to be a reliable tool in grading tubal closing ability.

Regulation of the middle ear pressure is assumed to be an important mechanism in the prevention as well as the treatment of middle ear disease in children. The middle ear pressure is normally regulated by active pressure equilibration such as swallowing, yawning and other movements of the jaws. The middle ear pressure can also be regulated passively by a pressure-induced opening of the tube without any tubal muscular activity. If pressure regulation is impaired, a negative middle ear pressure is induced by the gas absorption of the middle ear mucosa (Elnor, 1972).

However, negative middle ear pressures can also be induced by sniffing (Gray 1967, Lamp, 1973). Such observations were frequently made both in children and adults with adhesive otitis and retraction pocket cholesteatoma

of the middle ear (Magnusson, 1980). Thus, poor "active" pressure equilibration of the tube may be one possible cause of persistent negative middle ear pressure and middle ear disease; habitual sniffing, another.

Since the active equilibrating ability of the tube in children with middle ear disease is generally poor (Silverstein et al., 1966; Canteikin et al., 1976; Poulsen & Tos, 1977), alternative ways for regulating the pressure, e.g. tympanostomy with or without draining tubes as well as autoinflationary methods are assumed

Abbreviations and definitions

P_{rh}	rhinopharyngeal pressure
P_{ec}	ear canal pressure
P_{ch}	chamber pressure
$Pol_{rh\ v}$	pressure opening level, i.e. rhinopharyngeal overpressure that forces the tube open by Valsalva's manoeuvre
$Pol_{rh\ M}$	as above but by mouth-to-nose inflation
Pol_{rh}	$Pol_{rh\ v}$ or, if not measurable, $Pol_{rh\ M}$
Pol_{ch}	pressure opening level, i.e. overpressure in the middle ear that forces the tube open by deflation in a pressure chamber
$Pcl_{rh\ v}$	pressure closing level, i.e. overpressure in the middle ear when the tube has closed after Valsalva's manoeuvre
$Pcl_{rh\ M}$	as above but by mouth-to-nose inflation
Pcl_{rh}	$Pcl_{rh\ v}$ or, if not measurable, $Pcl_{rh\ M}$
Pcl_{ch}	pressure closing level, i.e. overpressure in the middle ear when the tube has closed after deflation in a pressure chamber
Pol_{rh}/t	rate of pressure increase in rhinopharynx from the start of inflation to the moment of tubal opening
$Prh_{max\ infl}$	maximal rhinopharyngeal overpressure during inflation
$Prh_{max\ defl}$	maximal rhinopharyngeal underpressure during deflation

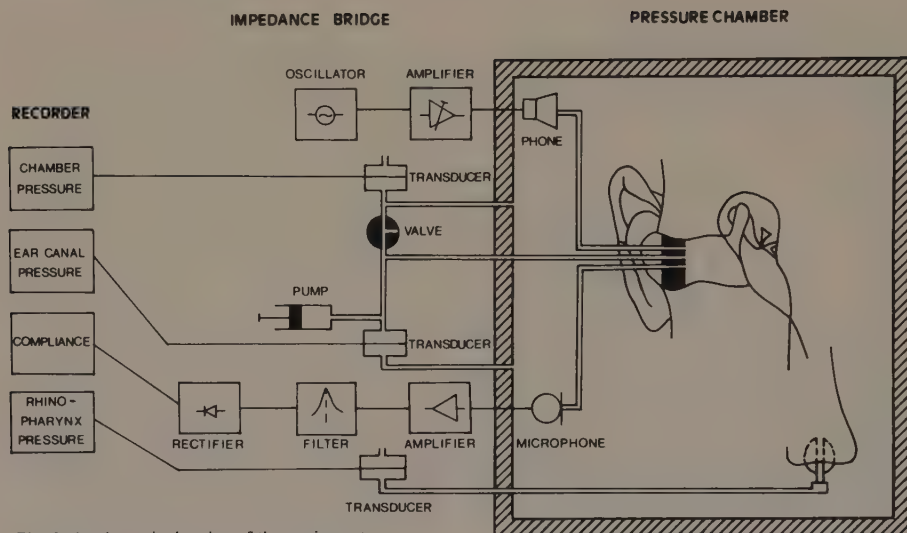


Fig. 1. A schematic drawing of the equipment.

to be therapeutically important. But opinions differ about the advantages of the voluntary change of middle ear pressure by autoinflation (Hunt-Williams, 1968; Shea, 1971; Fraser et al., 1977; Schwartz et al., 1978; Gottshalk, 1980).

However, no conclusions can be drawn on the importance of these manoeuvres and the role of the Eustachian tube in these respects in children with middle ear effusions without knowledge of their importance in normal children. Therefore, we focused our interest on to what extent otologically healthy children and adults can voluntarily change the middle ear pressure by inflationary and deflationary manoeuvres and on what factors decide the response rates. Mouth-to-nose inflation was designed in our clinic as an alternative to Valsalva's manoeuvre and these inflationary manoeuvres were investigated, since they offer a possibility of both qualitative and quantitative evaluation of inflation. As deflationary manoeuvres, sniffing as well as reversed Valsalva's manoeuvre were chosen.

In the presentation of our results we used

the nomenclature proposed by Ingelstedt (1978). The basis of this standardization is (a) whether or not the tube is opened by tubal muscles, and (b) the direction of air-flow through the tube. "Active" pressure equilibration capacity of the tube is called *muscular opening function*. "Passive" equilibration by a pressure difference between the middle ear and the rhinopharynx without any known tubal muscular activity is called *pressure opening function*. The residual middle ear pressure after a pressure-induced opening is used to express the *pressure closing function*. The equilibration of a negative pressure in the middle ear by muscular activity with an air-flow from the rhinopharynx to the middle ear is called *inhalation*. *Exhalation* designates air-flow from the middle ear to the rhinopharynx, i.e. equilibration of overpressure in the middle ear, by muscular opening of the tube. The term *inflation* is used to describe the air-flow to the middle ear from the rhinopharynx without any known tubal muscular activity and *deflation*, the air-flow from the middle ear to the rhinopharynx.

The aims of the present study were 1) to estimate the ability of otologically healthy children and adults to perform inflationary and deflationary manoeuvres; 2) to assess the pressure opening and closing functions by the inflationary manoeuvres and by deflation in a pressure chamber; and 3) to find out to what extent tubal and non-tubal factors affect the response rates of inflationary and deflationary manoeuvres.

MATERIAL AND METHODS

The material consisted of 58 otologically healthy children, aged 3–12 years (mean 7.0 years) and 61 adults, aged 17–73 years (mean 29.9 years). The criteria for acceptance as otologically healthy were: no history of recurrent acute otitis media, middle ear effusion, impairment of hearing or obstructing adenoid or allergy, no symptoms or signs of upper respiratory tract infection, normal otoscopic or otomicroscopic findings including examination with Siegle's pneumatic otoscope, pure tone hearing threshold within 0–20 dB (ISO standard 1964) and V-shaped tympanograms indicating air-filled middle ears. The same material was investigated in an earlier study of muscular opening function by the exhalation/inhalation test and of pressure opening and closing functions by the deflation test in a pressure chamber (Bylander et al., 1982).

Equipment

A schematic drawing of the equipment used is given in Fig. 1. An electroacoustic impedance bridge model ZO 70 with a probe frequency of 220 Hz (Madsen Electronics, Copenhagen, Denmark) was used for tympanometric measurements of the middle ear pressure and for indicating tubal openings and closings by changes in compliance. A pressure transducer (EMT 35, Siemens Elema, Stockholm, Sweden) with a pressure range of $\sim \pm 40$ kPa was used for recording rhinopharyngeal pressure (P_{rh}) by connecting the transducer to one nostril by means of a catheter and a nose olive.



Fig. 2. Performance of mouth-to-nose inflation.

These nasal recordings were accepted as representing the rhinopharyngeal pressure (see Fig. 1). The volume of air in the catheter and transducer was 30 ml. A pressure chamber and two pressure transducers (EMT 33 and EMT 35, Siemens Elema, Stockholm, Sweden), recording ear canal pressure (P_{ec}) and chamber pressure (P_{ch}), were used for assessing muscular opening function and pressure opening and closing functions of the tube. For a more detailed description of the pressure chamber tests, reference is made to Bylander et al. (1981, 1982).

The compliance, the ear canal pressure, the chamber pressure and the rhinopharyngeal pressure were synchronized and recorded on a multi-channel ink jet recorder (Minograph 81, Siemens Elema, Stockholm, Sweden). The recordings were performed at a chart speed of 10 mm/s, except for inflationary and deflationary manoeuvres when a chart speed of 100 mm/s

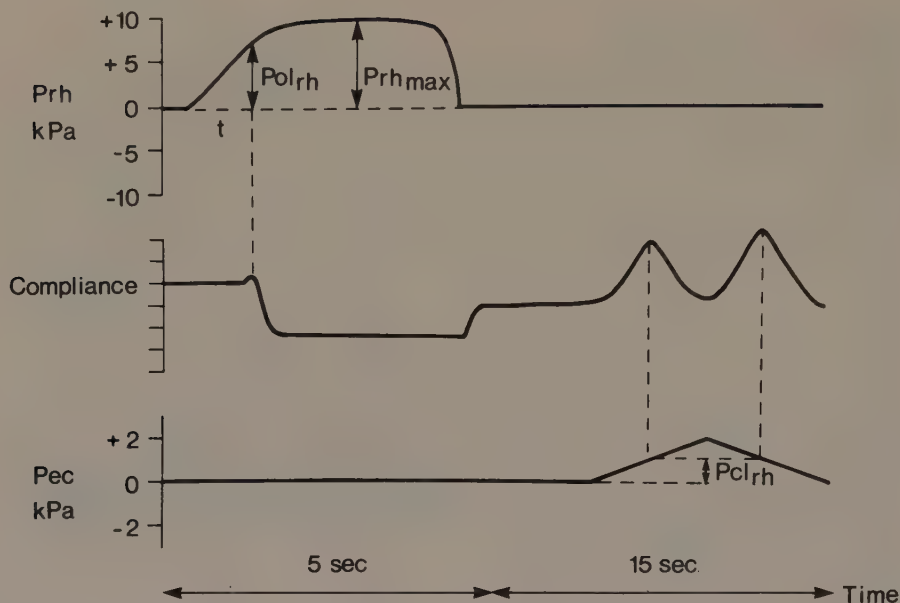


Fig. 3. Example of recording of rhinopharyngeal pressure (P_{rh}), compliance and ear canal pressure (P_{ec}), during an inflationary manoeuvre, with calculation of pressure opening level (P_{olrh}), pressure closing level (P_{clrh}) and

maximal rhinopharyngeal pressure (P_{rhmax}). t denotes time in seconds from the start of the inflation to the moment of tubal opening. For further details, see text.

was used. The transducers were calibrated by means of an alcohol manometer before and after each recording.

Performance

Informed consent of the children's parents was obtained before the tests. With the subject seated comfortably in the pressure chamber, the ear-probe was sealed air-tight in the left ear canal and the test procedure was explained. The small children needed an assistant in the chamber for instructions and entertainment. All recordings of the tests were performed by one and the same examiner as follows:

1. *Middle ear pressure* was initially recorded by tympanometry. Before each of the following procedures it was checked that the middle ear pressure was equilibrated with the

ambient pressure either by muscular opening of the tube or, when this was not possible, by means of the pressure chamber. The subject was instructed to avoid muscular opening during the following procedures 2-4.

2. *Inflationary manoeuvres.* The subjects were instructed how to perform *Valsalva's manoeuvre*, i.e. a forceful expiration against the closed nose. They could also check their rhinopharyngeal pressure during the manoeuvre by watching a pressure manometer connected to the system. This helped them to control that they performed the manoeuvre properly. *Mouth-to-nose inflation* was performed with a nose olive tightly connected to a catheter held in the mouth (Fig. 2). The subjects were instructed to blow as hard as they could through the catheter, forcing air from the oral cavity to the rhinopharynx.

Those who could create a positive pressure in the middle ear, qualitatively indicated by a change in the compliance curve, were called responders to inflation (infl+). The pressure levels in the rhinopharynx at which the Eustachian tube was opened by Valsalva's manoeuvre (Pol_{rhV}) and by mouth-to-nose inflation (Pol_{rhM}) were also quantitatively assessed (Fig. 3). The figure also shows the calculation of the maximal rhinopharyngeal pressure ($Prh_{max\,infl}$) during the inflationary manoeuvre. The rate of pressure increase (Pol_{rh}/t in kPa/s) in the rhinopharynx was calculated from the start of the inflation to the moment the tube opened. If the first manoeuvre was unsuccessful the subjects were allowed to try again twice.

The residual overpressure in the middle ear after a successful inflationary manoeuvre was recorded as the pressure closing level (Pcl_{rhV} and Pcl_{rhM}) (Fig. 3). In most ears the tube closed almost immediately after inflation and remained so, as shown by a stable compliance curve (Fig. 3). The Pcl_{rh} was measured by tympanometry about 5–10 sec after the manoeuvre.

3. Deflationary manoeuvres. The subjects were instructed to sniff, i.e. inspire forcefully with the mouth closed. One nostril was connected to the pressure transducer with a nose olive and a catheter. Those who could not create a negative pressure in the middle ear were instructed to perform a *reversed Valsalva's manoeuvre*, i.e. a forced inspiration with one nostril connected to the pressure transducer; the other nostril closed by the hand. A pressure manometer was connected to the recording system in order to help the subject to perform the test properly. Those who could create a negative pressure in the middle ear by either manoeuvre were called responders to deflation (defl+). If the first deflationary manoeuvre was unsuccessful, the subject was allowed to try again twice.

The underpressure created in the middle ear by successful deflation was recorded by tympanometry, and the maximal underpressure in

Table 1. Muscular opening function (tubal function groups I+II, and III+IV) and the results of inflation and deflation (infl+, defl+ =successful) in 58 children and 61 adults

The children are also distributed in age groups

Tubal function test	Children					Adults	
	3–5 yrs n=18	6–8 yrs n=25	9–12 yrs n=15	Total n=58	%	Total n=61	%
I+II	4	20	12	36	62	58	95
III+IV	14	5	3	22	38	3	5
Infl+	7	20	14	41	71	61	100
Defl+	0	6	8	14	24	21	34

the rhinopharynx during the tests ($Prh_{max\,defl}$) was read from the rhinopharyngeal pressure curve. The underpressure in the rhinopharynx at the moment the tube opened was also calculated.

4. Pressure opening and closing levels by the pressure chamber method. The decrease in chamber pressure required to create a relative overpressure in the middle ear sufficient to force the tube open was recorded as the pressure opening level (Pol_{ch}). The residual overpressure in the middle ear when the tube closed after the pressure opening was called the pressure closing level (Pcl_{ch}). The mean rate of pressure decrease in the chamber from ambient pressure to -7 kPa was 0.37 kPa/s.

5. Exhalation/inhalation test, i.e. active equilibration of a static pressure difference of 1 kPa across the eardrum induced by a decrease or an increase in chamber pressure. Depending on the results of equilibration of both over- and underpressures by the method of free choice, i.e. by swallowing, yawning and other movements of the jaw, the subjects were distributed among tubal function groups I–IV (Elnor et al., 1971) according to Bylander et al. (1981). Groups I+II could equilibrate both over- and underpressures and were therefore regarded as having good muscular opening function. Group III could equilibrate overpressure but not underpressure, and

Table II. Maximal rhinopharyngeal overpressure ($Prh_{\max \text{ infl}}$) in responders ($\text{infl}+$) and non-responders ($\text{infl}-$) to inflation

	$Prh_{\max \text{ infl}}$					
	Children			Adults		
	<i>n</i>	Mean	SD	<i>n</i>	Mean	SD
Infl+	41	7.49	± 2.94	61	8.41	± 3.08
Infl-	17	5.21	± 5.21	-	-	-
Total	58	6.82	± 3.03	61	8.41	± 3.08

group IV could not equilibrate any pressure at all applied during the test period. Groups III and IV were therefore assumed to have poor muscular opening function.

The performance of tests 4 and 5 have been described in detail previously (Bylander et al., 1982).

RESULTS

Inflationary manoeuvres and exhalation/inhalation test

Valsalva's manoeuvre was successful in 57 (93%) of the 61 adults and in 38 (66%) of the 58 children. The corresponding figures for mouth-to-nose inflation were 60 (98%) and 35 (60%). The difference between adults and children was significant in both tests ($p < 0.001$, χ^2 -test). All 61 adults could inflate their middle ears when allowed to try both manoeuvres, while 17 children of the 58 could not. Neither in adults nor in children was there any difference in the response rate of the two inflationary manoeuvres ($p > 0.05$, χ^2 -test).

The response rate of inflation also improved with the children's increasing ages as did the muscular opening function (Table I). In the younger children (3–5 years of age) the inflationary manoeuvres were less successful as compared with both children 6–8 years of age ($p < 0.05$) and 9–12 years of age ($p < 0.01$, Fisher's exact test). The muscular opening function was also less good in the younger children (3–5 years of age) as compared with both children 6–8 years of age ($p < 0.001$) and 9–12

years of age ($p < 0.01$, Fisher's exact test). There was, however, no difference between the two oldest age groups for neither the inflationary manoeuvres nor the muscular opening function ($p > 0.05$, Fisher's exact test).

Table II shows the maximal overpressure recorded in the rhinopharynx during the inflation tests. This pressure was significantly higher in the adults than in the children and also higher in the older children (9–12 years) than in the younger ones (3–5 years) ($p < 0.01$, Student's *t*-test). It is also seen from the table that the 41 children in whom the inflationary manoeuvres were successful were able to create a higher pressure in rhinopharynx than in the 17 in whom they were not ($p < 0.01$, Student's *t*-test).

Pressure opening levels (Pol). The pressure levels in the rhinopharynx at which the Eustachian tube was opened by Valsalva's manoeuvre (Pol_{rhv}) and mouth-to-nose inflation (Pol_{rhM}) are given in Table III. There was no significant difference between children and adults in the results of each manoeuvre ($p > 0.05$, Student's *t*-test); neither was there any significant difference between Pol_{rhv} and Pol_{rhM} within the groups ($p > 0.05$, Student's *t*-test, paired observations). Table III also gives

Table III. Pressure opening levels in the rhinopharynx and pressure closing levels in the middle ear by Valsalva's manoeuvre (Pol_{rhv} and Pcl_{rhv}), mouth-to-nose inflation (Pol_{rhM} and Pcl_{rhM}) and pressure opening and closing levels by deflation in a pressure chamber (Pol_{ch} , Pcl_{ch}) in kPa in normal children and adults

Pressure function test	Children			Adults		
	<i>n</i>	Mean	SD	<i>n</i>	Mean	SD
Pol_{rhv}	38	5.32	± 2.30	57	6.00	± 2.54
Pol_{rhM}	35	4.77	± 1.62	60	5.56	± 1.98
Pol_{ch}	55	3.86	± 1.08	60	4.19	± 1.53
Pcl_{rhv}	30	0.98	± 0.66	35	0.93	± 0.76
Pcl_{rhM}	28	1.04	± 0.47	34	1.06	± 0.86
Pcl_{ch}	54	1.17	± 0.72	56	1.32	± 0.89

n denotes number of subjects with accurate calculations

Table IV. Maximal rhinopharyngeal under-pressure ($Prh_{\max \text{ defl}}$) in kPa in responders ($\text{defl}+$) and nonresponders ($\text{defl}-$) to deflation

	$Prh_{\max \text{ defl}}$					
	Children			Adults		
	<i>n</i>	Mean	$\pm$ SD	<i>n</i>	Mean	$\pm$ SD
Defl+	14	-6.43	$\pm$ 1.81	21	-5.74	$\pm$ 1.71
Defl-	44	-4.41	$\pm$ 1.85	40	-5.34	$\pm$ 1.87
Total	58	-4.89	$\pm$ 2.01	61	-5.48	$\pm$ 1.81

the pressure levels at which the tube opened when the middle ear pressure was increased indirectly by a lowering of the chamber pressure (Pol_{ch}), as also shown in an earlier study (Bylander et al., 1982).

The mean rate of pressure increase by Val-salva's manoeuvre was 11.7 kPa/s ($SD \pm 10.2$, range 1.5–27.0) in the children and 11.6 kPa/s ($SD \pm 7.7$, range 1.2–39.2) in the adults. The corresponding values for mouth-to-nose inflation were 9.2 kPa/s ($SD \pm 7.8$, range 1.7–39.2) and 11.0 kPa/s ($SD \pm 7.0$, range 1.5–29.4). The rate of pressure increase during inflation was not related to the children's ages when calculated in different age groups ($p > 0.05$, Student's *t*-test).

Pressure closing levels (Pcl). The pressure closing levels, i.e. the residual overpressure in the middle ear after a successful inflation (Pcl_{rhV} and Pcl_{rhM}) and after passive opening of the Eustachian tube by deflation in the pressure chamber (Pcl_{ch}) are also given in Table III. There was no significant difference between adults and children in any of the tests ($p > 0.05$, Student's *t*-test). Neither was there any significant difference between Pcl_{rhV} and Pcl_{rhM} within the groups ($p > 0.05$, Student's *t*-test, paired observations). Fig. 4 shows the correlation between Pcl_{rhV} and Pcl_{rhM} in the two groups.

In what follows Pcl_{rhV} , or when this was not measurable Pcl_{rhM} , is denoted as Pcl_{rh} . There was no significant difference between Pcl_{rh}

and Pcl_{ch} ($p > 0.05$) in the children, while in the adults there was a difference ($p < 0.05$, Student's *t*-test, paired observations). Fig. 5 shows the correlation between Pcl_{rh} and Pcl_{ch} in the children and in the adults.

Relation of Pol_{ch} and Pcl_{ch} to inflationary manoeuvres. The 17 children with unsuccessful inflationary manoeuvres had significantly higher Pcl_{ch} (mean 1.45 kPa, $SD \pm 0.51$ kPa) than the others (mean 1.05 kPa, $SD \pm 0.54$ kPa) ($p < 0.05$, Student's *t*-test) but the Pol_{ch} did not differ significantly between the non-responders to inflation (mean 3.89 kPa, $SD \pm 1.14$) and the responders (mean 3.73 kPa, $SD \pm 1.21$).

Comments. Owing to leakage of the tube, limited pressure range of the chamber, and tuba aperta that made it impossible to establish any pressure differences across the eardrum some of the subjects are not accounted for in the results of Pol_{ch} and Pcl_{ch} . Before tympanometry was performed for recording Pcl_{rh} , some compliance curves were unstable because of slow leakage of air, spontaneous tubal opening or accidental muscular opening. Thus, only stable curves like the one in Fig. 3 and those few curves with a leakage to ambient pressure immediately after the manoeuvre, i.e. no measurable Pcl , were used in the analysis of the results of Pcl_{rh} , which explains the missing cases in Tables III, V and VI.

Reliability of the inflationary manoeuvres. The reliability of Pol_{rhV} and Pol_{rhM} was estimated from 2 or 3 recordings made on the same occasion in 44 adults and 36 children. The SD of repeated measurements, i.e. the total error of the method of Pol_{rhV} was ± 0.68 kPa and of Pol_{rhM} ± 0.80 kPa in the adults and ± 1.29 kPa and ± 1.18 kPa, respectively, in the children. The corresponding values of Pcl_{rhV} and Pcl_{rhM} were ± 0.22 kPa and ± 0.33 kPa for the adults and ± 0.28 kPa and ± 0.17 kPa for the children.

Deflationary manoeuvres

Fourteen of the 61 (23%) adults and 10 (17%) of the 58 children could deflate the middle ears by sniffing. Of those who could not sniff, 7

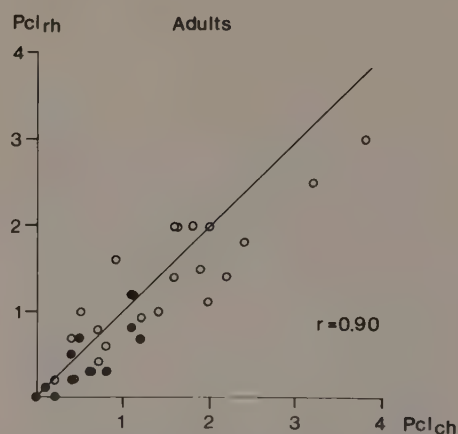
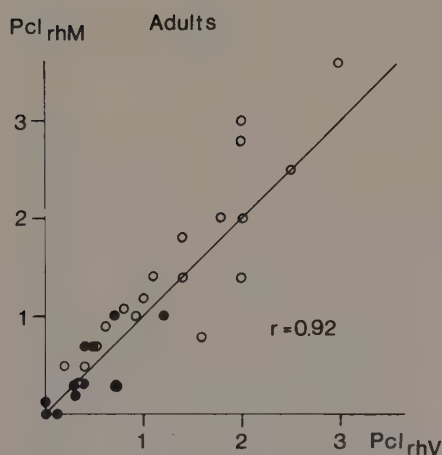
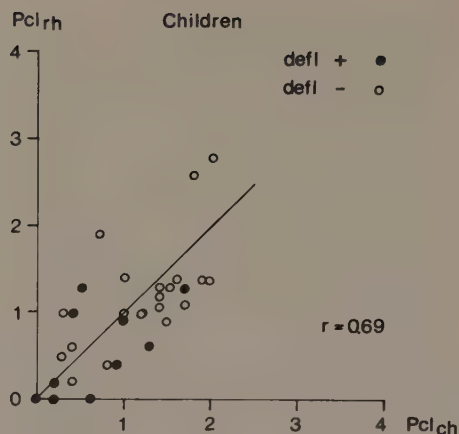
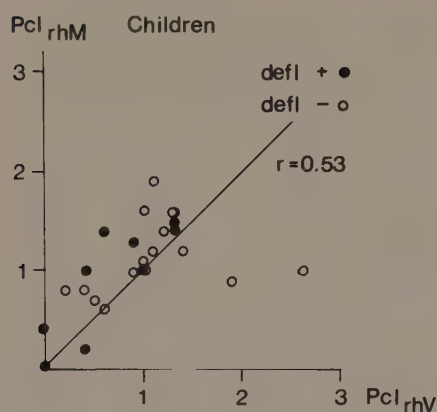


Fig. 4. Correlation between pressure closing levels by Valsalva's manoeuvre (Pcl_{rhV}) and by mouth-to-nose inflation (Pcl_{rhM}) in 25 children and 30 adults. r denotes correlation coefficient, (●) responders and (○) non-responders to deflation. The diagonal line represents the case where $Pcl_{rhV} = Pcl_{rhM}$.

Fig. 5. Correlation between pressure closing levels by Valsalva's manoeuvre or mouth-to-nose inflation (Pcl_{rh}) and by deflation in a pressure chamber (Pcl_{ch}) in 31 children and 34 adults. r denotes correlation coefficient, (●) responders and (○) non-responders to deflation. The diagonal line represents the case where $Pcl_{rh} = Pcl_{ch}$.

adults and 4 children could deflate the middle ear by reversed Valsalva's manoeuvre and thus 21 (34%) adults (11 men, 10 women) and 14 (24%) children (10 boys, 4 girls) were responders to deflation

Successful deflation varied with the chil-

dren's ages. None of the 18 children, 3–5 years of age, could deflate the middle ears in comparison with 6 of the 25 children 6–8 years of age ($p < 0.05$) and 8 of the 15 children, 9–12 years of age (Table I) ($p < 0.01$, Fisher's exact test).

Table V. Pressure opening and closing levels by deflation in a pressure chamber (Pol_{ch} , Pcl_{ch}), pressure closing level in the middle ear after inflationary manoeuvre (Pcl_{rh}) and Pol_{ch} minus Pcl_{ch} in kPa in adults with successful (+) and unsuccessful (-) deflation

Pressure function test	Adults						<i>p</i>
	Deflation +			Deflation −			
	<i>n</i>	Mean	SD	<i>n</i>	Mean	SD	
Pol _{ch}	21	3.29	±1.35	39	4.66	±1.42	<0.001
Pcl _{ch}	17	0.74	±0.54	39	1.57	±0.91	<0.001
Pcl _{rh}	14	0.48	±0.38	23	1.23	±0.75	<0.01
Pol _{ch} − Pcl _{ch}	17	2.61	±0.98	39	3.19	±0.88	<0.05

Table IV gives the maximal rhinopharyngeal underpressure induced during the deflationary manoeuvres ($Prh_{max\ den}$). This pressure was significantly more negative in the adults than in the children ($p < 0.05$, Student's *t*-test). It was also more negative in the children who responded to deflation than in those who did not ($p < 0.01$, Student's *t*-test). No such difference was seen in the adults.

The mean underpressure in the middle ear induced by deflationary manoeuvres was -1.55 kPa ($SD \pm 1.53$, range $-4.9-0$) in the children and -1.0 kPa ($SD \pm 1.53$, range $-4.3-0$) in the adults. The mean rhinopharyngeal underpressure, at which the tube opened, was -4.78 kPa ($SD \pm 2.18$) in the children and -4.88 ($SD \pm 1.94$) in the adults. The difference between the children and the adults was not significant ($p > 0.05$, Student's *t*-test).

Relation of Pol_{ch} , Pcl_{ch} and Pcl_{rh} to defla-

tionary manoeuvres. Adults as well as children who responded to deflation had lower mean values of Pol_{ch} , Pcl_{ch} and Pcl_{rh} than the non-responders (Tables V and VI). The differences were significant for the adults as well as for the children ($p < 0.05$ – $p < 0.001$, Student's *t*-test). In Figs. 4 and 5 are also seen the individual Pcl in responders and non-responders to deflation.

The mean difference between Pol_{ch} and Pcl_{ch} reflecting the intraluminal factors of the total closing forces did not differ significantly between children who could deflate and those who could not ($p > 0.05$, Student's *t*-test). However, in the adults the mean Pol_{ch} minus Pcl_{ch} was significantly lower in the responders to deflation than in the non-responders ($p < 0.05$, Student's *t*-test).

Relation of middle ear pressure and muscular opening function to deflationary manoeu-

Table VI. Pressure opening and closing levels by deflation in a pressure chamber (Pol_{ch} , Pcl_{ch}), pressure closing level in the middle ear after inflationary manoeuvre (Pcl_{rh}) and Pol_{ch} minus Pcl_{ch} in kPa in children with successful (+) and unsuccessful (-) deflation

Pressure function test	Children						<i>p</i>
	Deflation +			Deflation –			
	<i>n</i>	Mean	SD	<i>n</i>	Mean	SD	
Pol _{ch}	13	3.21	±1.27	42	3.98	±1.10	<0.05
Pcl _{ch}	12	0.72	±0.47	42	1.30	±0.73	<0.05
Pcl _{rh}	11	0.63	±0.51	22	1.21	±0.48	<0.01
Pol _{ch} –Pcl _{ch}	12	2.50	±1.08	42	2.72	±0.77	>0.05

Table VII. Initial middle ear pressure in kPa in children and adults with successful (+) and unsuccessful (–) deflation and in tubal function groups I+II and III+IV

	P _m					
	Children			Adults		
	n	Mean	SD	n	Mean	SD
Defl+	14	–0.13	±0.27	21	–0.02	±0.04
Defl–	44	–0.34	±0.56	40	–0.04	±0.19
I+II	36	–0.12	±0.37	58	–0.03	±0.13
III+IV	22	–0.60	±0.67	3	–0.32	±0.30
Total	58	–0.29	±0.51	61	–0.04	±0.15

ures. Neither in the children nor in the adults was there any significant difference in the distribution of the initial middle ear pressures between responders and non-responders to deflation ($p > 0.05$, χ^2 -test). As can be seen from Table VII, the children as well as the adults with poor muscular opening function (groups III and IV) had lower pressures in the middle ear than those with a good muscular opening function (groups I and II). The difference in distribution was significant ($p < 0.05$, χ^2 -test). Thus, the initial negative middle ear pressures were related to poor muscular opening function and not to successful deflation.

All the 21 adult responders to deflation belonged to tubal function group I, 12 of the 14 children who responded to deflation belonged to group I, one child belonged to group II and the remaining child to group III.

DISCUSSION

Valsalva's manoeuvre, once developed to assess tubal patency, has for many years been used in otological practice as an autoinflationary method in the treatment of middle ear effusion and for pressure equilibration in aviation and diving. An unsuccessful Valsalva's manoeuvre is thought to be due to tubal dysfunction or to incorrect technical performance of the manoeuvre (Watson, 1961). Further-

more, sniffing (deflation) has recently been claimed to be a primary pathogenic factor for middle ear disease by inducing negative middle ear pressures leading to adhesive otitis media and retraction pocket cholesteatoma, both in children and in adults (Magnusson, 1980). These manoeuvres, believed to be important in the pathogenesis and treatment of middle ear effusions, seem to merit further investigation. It was therefore thought worth while to try to find out to what extent otologically healthy children and adults can inflate and deflate the middle ear and to ascertain what factors decide the response rate of these manoeuvres.

Only 66% of the normal children in this material, compared with 93% of the adults, could increase the middle ear pressure by Valsalva's manoeuvre. Though several reports on normal adults, with results similar to ours, are available (Chunn, 1960; Elner et al., 1971; Groth et al., 1980) hardly any studies have been made in children. Cantekin et al. (1976) found that 2–6 year old children with middle ear effusions were unable to inflate the middle ears by Valsalva's manoeuvre. Bluestone et al. (1981) recently reported that 6 of 7 children (3–16 years old) who had a traumatic perforation but who were otherwise otologically normal, could perform the Valsalva manoeuvre, as compared with only 11 of 28 children (3–15 years old) who had a retraction pocket or a cholesteatoma. These results suggested a relationship between unsuccessful Valsalva's manoeuvre and middle ear disease. But since in our study as many as 13 of the 18 normal children, 3–5 years old, could not inflate by this manoeuvre, other reasons are of importance. Using mouth-to-nose inflation another 2 children in this age group were successful.

Initially, the mouth-to-nose inflation method was designed in our clinic as an easier alternative to Valsalva's manoeuvre, since many children perform the latter method with an incorrect technique, e.g. with closed glottis. However, introduction of a pressure manometer as an aid to check the correct per-

formance of the Valsalva's manoeuvre, obviously helps the examinees to perform the manoeuvre properly, since then there was no difference in the response rate between the methods.

When both Valsalva's manoeuvre and mouth-to-nose inflation were allowed, 100% of the normal adults could inflate the middle ears, indicating that earlier failures were due to incorrect technique rather than to tubal dysfunction. But still only 71% of the children could inflate the middle ears.

Seventeen per cent of the children and 23% of the adults could deflate the middle ears by sniffing. In order to eliminate interindividual differences in nasal resistance, sniffing with closed nose, i.e. the reversed Valsalva's manoeuvre was included. When both manoeuvres were allowed 24% of the children and 34% of the adults could deflate the middle ears, thus showing that reversed Valsalva's manoeuvre is the more effective. By introducing the pressure manometer a moment of competition in the deflationary manoeuvres was achieved, which certainly increased the number of responders to deflation.

Our results of deflation in normal adults are in good agreement with those of Magnusson (1980), who found 33% sniffing responders in normal adults. However, in his study the subjects had perforated eardrums and often performed a Valsalva manoeuvre before the sniffing test. Falk (1981) found only 14% successful sniffers in normal subjects (5–79 years old). Since our method in contrast with Falk's allowed continuous recording of compliance, also those few responders with no residual middle ear pressure after deflation could be recorded. In spite of this his results were still lower compared with ours.

In this study the response rate of inflationary and deflationary manoeuvres was found to increase with the children's ages (Table I). In order to find an explanation for the difference in response rate between children and adults as well as the improvement with age, we recorded the maximal over- and underpressures

induced in the rhinopharynx during the manoeuvres, irrespective of whether tubal opening occurred or not. These pressures were of significantly lower numerical values in the children (lowest in the youngest children 3–5 years of age) than in the adults. Furthermore, the children with successful inflation or deflation had significantly higher maximal rhinopharyngeal over- and underpressures, respectively, than the others. In the adults there was no such a difference between responders and non-responders to deflation.

These results clearly showed that in children the rhinopharyngeal pressure levels during the manoeuvres decide the tubal opening and closing ability. The capacity to create a sufficiently high rhinopharyngeal over- and underpressure in children depends on a variety of factors that change with age, such as the anatomy of the airways, including the magnitude of dead space, muscular effort and neuromuscular coordination of respiratory movements as well as motivation and the comprehension to perform the test properly. The nasal resistance is known to be of great importance; when increased it facilitates the development of rhinopharyngeal underpressure (Gray, 1967). The smaller dead space in the respiratory system including smaller epipharyngeal volume due to the adenoid in children would seem to favour the ability to create underpressures in the rhinopharynx as compared to adults. However, the rhinopharyngeal underpressures in the children who responded to deflation were not significantly greater than in the corresponding adults. Furthermore, the youngest children, having the smallest dead space, nevertheless had the smallest rhinopharyngeal underpressures and consequently the poorest response rate of deflation.

The inflationary manoeuvres were also quantitatively assessed by measuring the pressure opening and closing levels (Pol_{rh} and Pcl_{rh}), which reflect the tubal closing forces. Earlier studies have shown that the pressure opening levels of the tube are influenced by

the rate of pressure change induced (Andréasson et al., 1976; Cantekin et al., 1977; Ivarsson et al., 1979). This rate dependence was also confirmed in this study. Subjects with a rate of pressure increase of ≤ 5.0 kPa/s had significantly lower mean Pol than the group with a rate of ≥ 20.0 kPa/s ($p < 0.001$, Student's *t*-test). The rate dependence of Pol is related to the venous decongestion of the mucosa (Andréasson et al., 1976). Cantekin et al. (1977) suggested that viscous and elastic properties of the mucus of the tube also might be of importance.

Despite substantial interindividual differences, the mean pressure opening levels by Valsalva's manoeuvre and mouth-to-nose inflation did not differ significantly in the children or in the adults. Since the Pol values of the two manoeuvres were of the same magnitude they were regarded as equivalent, not involving any known tubal muscular activity, like Politzer's and Frenzel's manoeuvres, which consequently have lower opening pressures than Valsalva's manoeuvre (Chunn, 1960; Misurya, 1975). Politzer's and Frenzel's manoeuvres would therefore seem to be more appropriate as autoinflationary methods, but they are more difficult to perform voluntarily by children.

The pressure opening levels by Valsalva's manoeuvre have also been evaluated by Perlmann (1939), Cantekin et al. (1976), Gersdorff (1977), Kumazawa et al. (1977), Magnusson (1980) and others. Since they did not record the rates of pressure increase in the rhinopharynx, the interindividual comparisons are less valuable.

For completion and comparison the pressure opening and closing levels were also recorded by inducing deflation in a pressure chamber. In the pressure chamber method a constant defined rate of pressure decrease was created, thus in contrast with the variable rates of pressure increase by inflation, which were on the average 25 times higher. Since Pol is known to be rate-dependent, a comparative statistical analysis of this variable by the two

methods was considered pointless. A comparison of Pcl, obtained after pressure opening from the two directions of the tube, was however, performed, since it was not known whether Pcl is rate-dependent or not. Finding a strong correlation between Pcl_{rh} and Pcl_{ch} in both children and adults it seems possible to conclude the Pcl, unlike Pol, is not influenced by the rate of pressure change to the same degree.

In order to find out whether any tubal factors affect the response rate of inflation in children we compared successful and unsuccessful children in respect of Pol_{ch} and Pcl_{ch}. We found that non-responders had both higher Pol_{ch} and Pcl_{ch}, but the difference was significant only for Pcl_{ch}. Thus, not only non-tubal factors, such as age and rhinopharyngeal pressures, but also tubal factors influence the response rate of inflation.

What decides the capacity to deflate? In the adults it was shown to be dependent on tubal factors alone, i.e. Pol_{ch}, Pcl_{ch} and Pcl_{rh}, since the mean values were all significantly lower in the adults who could deflate the middle ears than in the group which could not. Also in the children successful deflation was shown to depend on the same variables, besides the previously mentioned ability to induce sufficient underpressures in the rhinopharynx. This relation of low Pcl_{ch} and successful deflation in both children and adults was described in an earlier preliminary report (Bylander, 1980). Magnusson (1980) also found low Pol and Pcl in responders to sniffing, but his results were not statistically verified.

All our normal children and adults who responded to deflation had good muscular opening function which may explain the absence of persistent negative middle ear pressures after deflation in those subjects. Instead, negative middle ear pressures in normals seem to be caused by poor muscular opening function rather than by successful deflation.

Clinical considerations

Judging from observations made in this study,

it would appear warranted to conclude that if autoinflationary manoeuvres are used as an alternative method in the treatment of middle ear disease in children, Valsalva's manoeuvre seems to be useful only after careful instructions and training or using aids like the visible pressure manometer. Mouth-to-nose inflation is recommended as a supplementary method, especially for small children and for those few adults who never properly master the technique of Valsalva's manoeuvre. Both tubal and non-tubal factors influence the response rate to inflation, and especially in children it is of greatest importance to make sure that sufficiently great rhinopharyngeal over- or underpressure is induced before any further conclusions regarding the function of the Eustachian tube are drawn from the results of inflationary and deflationary manoeuvres. Furthermore, comparison of individual pressure opening levels by inflationary manoeuvres requires a constant rhinopharyngeal rate of pressure increase.

Successful deflation is not pathological *per se*, as pointed out in an earlier preliminary report (Bylander, 1980), confirmed by Falk (1981). On the other hand, a combination of poor muscular opening function, low pressure opening and closing levels and habitual deflation seem to be a possible mechanism for inducing a persistent negative middle ear pressure, which might lead to middle ear disease.

However, the pressure closing level of the Eustachian tube, assumed to reflect the extraluminal closing forces, proved a rather constant and reliable variable measured either with the pressure chamber method or inflationary manoeuvre and seems to be a suitable tool in grading the closing ability of the tube.

ZUSAMMENFASSUNG

Um die Druckausgleichs- und Schließungsfunktion der Eustachischen Röhre sowohl qualitativ als auch quantitativ auszuwerten, wurden verschiedene Inflations- (z. B. Valsalva's) und Deflationsmanöver (z. B. Schnüffeln) bei 58 Kindern und 61 Erwachsenen untersucht, bei denen die Ohren gesund waren. Im Vergleich zu 100 % der Erwach-

senen konnten nur 71 % der gesunden Kinder den Mittelohrdruck bei Inflation voluntarisch erhöhen. Die Fähigkeit, das Mittelohr bei Deflation zu evaluieren, betrug 24 % bei den Kindern und 34 % bei den Erwachsenen. Der erreichte Rhinopharynxdruck war vom Alter abhängig und bestimmte zum Teil, ob ein Inflationsmanöver gelang oder nicht. Auch die tubaren Faktoren waren für die Inflations- und Deflationsfähigkeit von Bedeutung. Es bestand ein deutlicher Zusammenhang zwischen niedrigem Öffnungs- und Schließungsdruck und geglückter Deflation. Negativer Mittelohrdruck bei normalen Kindern beruhte eher auf schlechter muskularer Öffnungsfunktion als auf geglückter Deflation. Der Schließungsdruck der Tuba scheint ein zuverlässiger Maßstab für den Schließungsfähigkeitsgrad zu sein.

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CHANGES IN EUSTACHIAN TUBE FUNCTION WITH AGE IN CHILDREN WITH NORMAL EARS

A Longitudinal Study

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Abstract. A longitudinal study of the Eustachian tube function by different pressure equilibration tests was performed during 1½–3 years in 44 otologically healthy children, 3–12 years of age. The muscular opening function improved significantly with increasing age. The improvement was most frequent during pre-school ages (3–7 years). Also the tympanometrically measured middle ear pressure, related to the muscular opening function, tended to normalize during the follow-up study. The pressure opening and closing functions, reflecting the tubal closing forces, did not, however, change during the observation time. All the children with poorest muscular opening function at the initial test improved; none developed persistent middle ear disease during the follow-up. Using this standardized exhalation/inhalation test of the pressure equilibrating function of the tube it seems possible to grade the muscular opening function in a valid way. It is argued that the main cause of poor muscular opening function in children is not only due to anatomical differences of the skull base, the tube and peritubal structures but also to the immaturity of the neuromuscular system during childhood.

Impaired function of the Eustachian tube is regarded to be of major importance in the pathogenesis of middle ear effusions (MEE). Since MEE is most common in childhood, it seems to be of special interest to study the tubal function in children. Previously, several authors have found poor muscular opening function, i.e. poor "active" pressure equilibration capacity of the tube in children with MEE (Silverstein et al., 1966; Bluestone et al., 1974; Briggs et al., 1976; Poulsen & Tos, 1977; Spillman, 1977). However, there is no conclusive evidence indicating tubal dysfunction as a primary etiologic factor.

In order to distinguish between cause and

effect it seems necessary to evaluate tubal function in long-term studies not only in children with MEE but also in those who are otologically healthy. Comparative studies between children and adults with normal ears have been performed, showing much poorer results of the exhalation/inhalation test, i.e. the "active" pressure equilibration test, in children than in adults, and poorest results in the youngest children. The pressure opening and closing functions, i.e. the "passive" pressure equilibration functions, reflecting the tubal closing forces, however, did not differ between normal children and adults or between different age groups of the children (Bylander et al., 1981, 1982a).

In order to further evaluate the changes in tubal function with age, a longitudinal study was designed in which children, initially selected as otologically healthy, were repeatedly tested during three years. Since long-term results of the muscular opening function with the exhalation/inhalation test in normals are lacking and its stability over time has been questioned, it was thought worth while to investigate this function in repeated tests over time in normal adults as well. Adults were included since, unlike children, they were not expected to show a changed tubal function with age.

The aims of the present follow-up were 1) to study the influence of age on different variables of the pressure equilibrating functions of

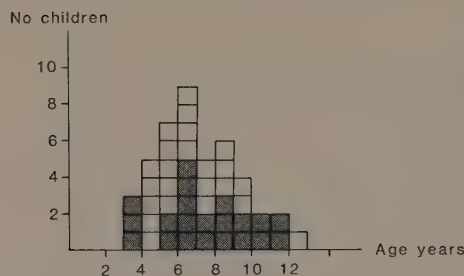


Fig. 1. Age distribution at the entry into the study of 44 normal children, in which the tubal muscular opening function was retested after 1½ years. Of these, 21 children (filled squares) were followed up during 3 years.

the Eustachian tube; and 2) to find out if poor muscular opening function resulted in middle ear disease.

MATERIAL

In an earlier paper were reported the results of two variables of "active" pressure equilibration functions; muscular opening function and tympanometrically measured middle ear pressure in 85 otologically healthy children, 3–12 years old (mean age 7.4) (Bylander et al., 1981). In this follow-up, 44 of these children were retested 18 ± 3 months (1½ years) later, and 21 of these on a third occasion 36 ± 3 months (3 years) after the initial test. The age distribution of the children is seen in Fig. 1.

The pressure opening and closing functions obtained by deflation in a pressure chamber and by inflationary and deflationary manoeuvres were studied earlier in 58 otologically healthy children (Bylander et al., 1982a, 1982b) and 39 of these (mean age 6.4), included in the present report, were retested after 18 ± 3 months.

The children in this follow-up did not differ statistically from the original material in respect of age and sex distribution and results of the different tubal function tests, and were therefore regarded as a representative sample.

All the children were primarily classified as

otologically healthy by the following criteria: no history of recurrent acute otitis media, middle ear effusion, impairment of hearing, or of obstructing adenoid or allergy; no history of recent upper respiratory tract infection (URI); and no symptoms or signs of URI when tested; normal otoscopic or otomicroscopic findings including examination with Siegle's pneumatic otoscope; pure tone hearing thresholds within 0–20 dB (ISO standard 1964); and V-shaped tympanograms indicating air-filled middle ear spaces.

To evaluate the variation over time in the results of the exhalation/inhalation test, 24 adults (mean age 28.2) with normal ears, selected on the basis of the same criteria as the normal children, were tested repeatedly (2–5 times) during 6–36 months, altogether 61 times.

METHODS

Fig. 2 shows a schematic drawing of the equipment. An impedance bridge model ZO 70 with probe frequency 220 Hz (Madsen Electronics, Copenhagen, Denmark), a pressure chamber with a pressure range of ± 7 kPa and three external pressure transducers (Elema Schönder, Stockholm, Sweden) and an ink-jet recorder (Mingograph 81, Siemens Elema) were used for the recordings. All tests and retests were performed with the same equipment, procedure and by the same examiner, so as to keep external test conditions as constant as possible. Informed consent from the parents of the children was obtained before the tests. Only the left ear was measured each time. The child was seated comfortably in the pressure chamber and the test procedure was explained. The small children needed an assistant in the chamber for instruction and entertainment.

The following tubal pressure equilibration function tests were performed:

1. *Initial middle ear pressure* was recorded with tympanometry. Before each of the following tests it was checked that the middle ear

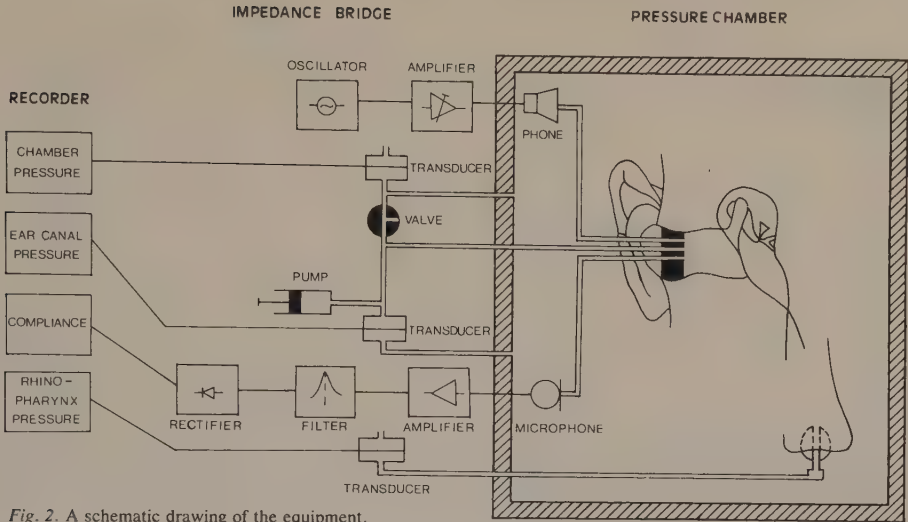


Fig. 2. A schematic drawing of the equipment.

pressure was equilibrated with ambient pressure either by "active" pressure equilibration of the tube or, if this was not possible, by means of the pressure chamber.

2. *Muscular opening function* by the exhalation/inhalation test, i.e. "active" equilibration of a static pressure difference of 1 kPa across the eardrum induced by a decrease or an increase in chamber pressure. Depending on the results of equilibration of both over- and underpressures by the equilibration method of free choice, i.e. by swallowing, yawning and other jaw movements, the subjects were distributed among tubal function groups I–IV according to Elner et al. (1971) modified by Bylander et al. (1981). Group I could equilibrate both over- and underpressures completely, group II partially. Group III could equilibrate overpressure partially but underpressure not at all, and group IV could not equilibrate any pressure applied during the test period. Groups I and II are therefore considered to correspond to good muscular opening function and groups III and IV to poor.

3. Pressure opening and closing functions

by deflation in a pressure chamber. The decrease in chamber pressure required to create a relative overpressure in the middle ear sufficient to force the tube open passively was recorded as the pressure opening level (Pol_{ch}). The residual overpressure in the middle ear when the tube closed after the pressure opening was called the pressure closing level (Pcl_{ch}) (Fig. 2). The mean rate of the pressure decrease in the chamber from ambient pressure to -7 kPa was 0.37 kPa/s. The child was not allowed to equilibrate by muscular opening during this and the following test.

4. *Inflationary manoeuvres*. The subject was instructed how to perform Valsalva's manoeuvre and mouth-to-nose inflation. The mouth-to-nose inflation was performed with a nose olive connected to a catheter held in the mouth. The child was then instructed to blow forcefully through the catheter, forcing air from the oral cavity to the rhinopharynx. A pressure manometer connected to the system helped the subject to perform Valsalva's manoeuvre correctly.

Those who could build up an overpressure

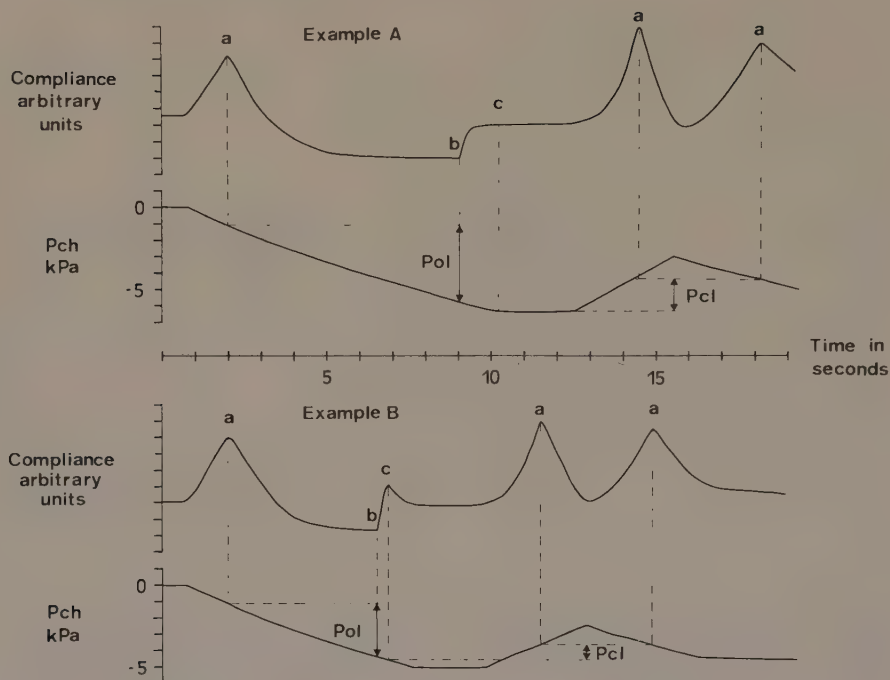


Fig. 3. Examples of recordings of compliance and chamber pressure (P_{ch}) with calculation of pressure opening levels (Pol) and pressure closing levels (Pcl). (a) denotes the neutral positions of the eardrum=relative zero pressures in the middle ear; (b) moment of pressure opening;

and (c) pressure closing of tube. In example A, after pressure opening, the middle ear pressure was constant, i.e. the tube was continuously leaking between (b) and (c). In example B the tube opened and closed intermittently during chamber pressure decrease.

in the middle ear by either inflationary manoeuvres, qualitatively indicated by a change in the compliance curve, were called responders to inflation (*infl+*). The residual overpressure in the middle ear after a successful manoeuvre was quantitatively recorded as the pressure closing level (Pcl_{rh}), measured by tympanometry 5–10 sec after the manoeuvre (Fig. 3).

5. Deflationary manoeuvres. The subject was instructed to inhale forcefully with one nostril connected to the pressure transducer, the other open (sniff) or closed (reversed Valsalva's manoeuvre). Those who could build up a negative pressure in the middle ear by either

manoeuvre were called responders to deflation (*defl+*). If the first inflationary or deflationary manoeuvre was unsuccessful, the subjects were instructed to try again twice.

The equipment and performance of the tests have been described in detail elsewhere (Bylander et al., 1981, 1982a, 1982b).

RESULTS

Muscular opening function by the exhalation/inhalation test

In children. The results of the exhalation/inhalation tests expressed in tubal function groups I–IV in 44 normal children tested and retested

Table I. Distribution of muscular opening function in tubal function groups I-IV in 44 normal children initially tested (Test 1) and retested after 1 1/2 years (Test 2)

Tubal function groups	<i>Test 2</i>				Total number of test 1
	I	II	III	IV	
<i>Test 1</i>					
I	19	2	1	—	22
II	3	—	—	—	3
III	2	4	3	—	9
IV	1	1	8	—	10
Total number of test 2	25	7	12	—	44

after 1 1/2 years showed significant improvement with time ($p < 0.01$, Sign test¹) (Table I). With increasing age 19 children (mean age 5.5) improved and 3 (mean age 5.3) deteriorated. Of the 22 children who did not change, 19 (mean age 8.2) already belonged to the best group (group I). As seen from the table all 10 children (mean age 5.1), who belonged to tubal function group IV at the initial test, improved at the retest; 8 to group III, one to groups I and II, respectively. The results of the exhalation/inhalation test in the 21 children who were followed up during 3 years are given in Fig. 4. After 1 1/2 years 9 children (mean age 6.2) improved, 10 (mean age 8.1) did not, of which 9 already belonged to group I, and 2 deteriorated from group I to groups II and III, respectively. One and a half years later still 5

Table II. Middle ear pressures in kPa in 21 children with normal ears followed up during 3 years

Time	P _m		
	Mean	SD	SEM
Initial test	-0.40	±0.51	±0.11
1 1/2 years later	-0.19	±0.50	±0.11
3 years later	-0.18	±0.33	±0.07
Difference initial test-retest			
3 years later	-0.22	±0.39	±0.09

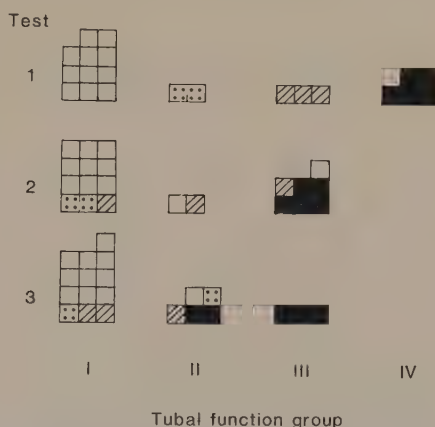


Fig. 4. Distribution of tubal function groups I-IV in 21 normal children tested (1) and retested after 1 1/2 years (2) and 3 years (3). At entry into the study unfilled squares denote children in group I, dotted squares children in group II, striped squares children in group III, and filled squares children in group IV.

children (mean age 6.9) improved and only one, initially belonging to group II, returned from group I to group II. The improvement of the muscular opening function during 3 years was also significant ($p < 0.05$, Sign test).

In adults. The muscular opening function expressed in tubal function groups I-IV remained stable during all tests in 20 of the 24 adults repeatedly tested during 6-36 months. Eighteen remained in group I at one or two retests, and 2 in group III at 4 respectively 5 test occasions. Only minor variations in muscular opening function were found in the remaining 4; 3 improved from group II to I and one from group III to II and remained there at two further tests.

Middle ear pressure

The results of the tympanometrically measured middle ear pressures in 21 children during 3 years are provided in Table II. As shown

¹ Siegel, S. 1956. *Nonparametric Statistics*. McGraw-Hill.

Table III. Pressure opening and closing levels in kPa by deflation in a pressure chamber (Pol_{ch} and Pcl_{ch}) in 39 children and pressure closing levels from stable curves by deflationary manoeuvres (Pcl_{rh}) in 22 children, with normal ears at initial test and retest 1 1/2 years later

Time	Pol_{ch} , $n=39$			Pcl_{ch} , $n=39$			Pcl_{rh} , $n=22$		
	Mean	SD	SEM	Mean	SD	SEM	Mean	SD	SEM
Initial test	3.67	± 1.20	± 0.19	1.24	± 0.78	± 0.12	1.06	± 0.58	± 0.12
1 1/2 years later	3.68	± 1.08	± 0.17	1.24	± 0.85	± 0.14	0.98	± 0.58	± 0.12
Difference initial test-retest	-0.01	± 0.79	± 0.13	0.00	± 0.54	± 0.09	0.08	± 0.50	± 0.11

in the table, the mean middle ear pressure became less negative with time. The difference in middle ear pressure between the initial test and the retest 3 years later was significant ($p < 0.05$, Student's t -test, paired observations). However, the middle ear pressures in the 44 children followed up for 1 1/2 years did not change significantly ($p > 0.05$, Student's t -test, paired observations).

Pressure opening and closing functions by deflation test in a pressure chamber

The pressure opening levels (Pol_{ch}) and pressure closing levels (Pcl_{ch}) were compared with 1 1/2 years interval in 39 children (Table III). Neither Pol_{ch} nor Pcl_{ch} showed any significant differences between tests (Student's t -test, paired observations). Fig. 5 shows the individual results of Pol_{ch} and Pcl_{ch} in the two tests. During decreasing chamber pressure, mainly two different patterns of the tubal closing function were seen (Fig. 3). At the initial test, 24 tubes worked as a constant pressure regulator after pressure opening (Example A, Fig. 3), which means that air was continuously leaking from the middle ear during the decrease in chamber pressure. In 11 children the tube closed almost immediately after the pressure opening (Example B, Fig. 3), and in another 4 children several pressure openings and closing occurred before the pressure decrease of the chamber was stopped. Thus, those tubes worked as pressure regulators by intermittent opening and closing. At the retest, 33 of

the 39 children had unchanged patterns of the tubal closing function, 5 curves had changed from unstable (Example B) to stable patterns (Example A), and one curve had changed into the reverse direction ($p > 0.05$, Sign test).

Pressure opening and closing functions by inflationary and deflationary manoeuvres

The results of the inflationary and deflationary manoeuvres in 39 children tested and retested 1 1/2 years later are shown in Table IV. The response rates of both inflationary and deflationary manoeuvres improved with time. Only one of the 32 responders to inflation at the initial test changed to a non-responder in the second test, and 4 of the 7 non-responders to responders. Corresponding results of the deflation test showed that 3 of 11 responders changed into non-responders and vice versa for 5 of the 28 non-responders. The pressure closing levels (Pcl_{rh}), i.e. the residual pressure in the middle ear after the inflationary manoeuvres, calculated in those who were responders to inflation and had stable curves, were compared between the two test occasions as well as with Pcl_{ch} (Table III). No significant difference was seen ($p > 0.05$, Student's t -test, paired observations).

Relation of muscular opening function and middle ear status

Of the 19 children with poor muscular opening function, i.e. in tubal function groups III and IV at the initial test, 16 improved at the retest

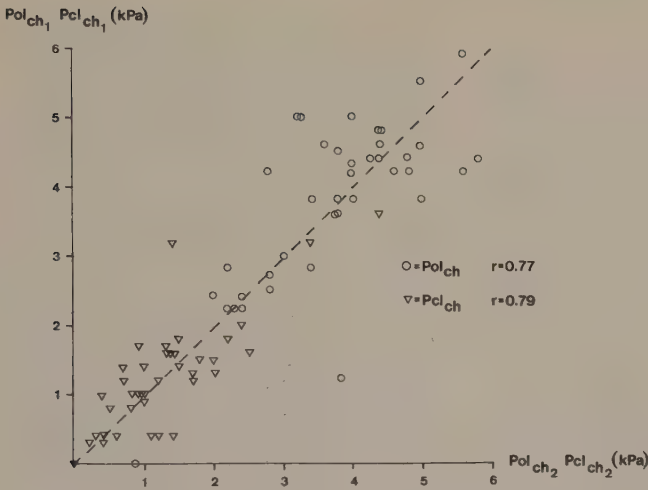


Fig. 5. Distribution of Pol_{ch} and Pcl_{ch} on two test occasions with 1 ½ years interval in 39 otologically healthy children. The diagonal line represents the cases where Pol_{ch1} = Pol_{ch2} and Pcl_{ch1} = Pcl_{ch2}. r denotes correlation coefficient.

after 1 ½ years, whereas only 3 remained in group III. Eight of the 19 children were tested after 3 years and at this time only 3 remained in groups III and IV. None of these 19 children developed any persistent middle ear disease during the observation time.

Comments. During the follow-up 3 children had one episode of acute otitis media. Two of them belonged to tubal function group I at all tests, one of them was a girl with a tuba aperta (no measurable Pol_{ch} and Pcl_{ch}). Even in recumbent position her tubes remained open at the retests. The third child, initially in group IV, improved to group III at the retest after 3 years. In addition, one child in group III had two episodes of acute otitis media during the first year of the follow-up. Furthermore, 7 children had large underpressures (more negative than -2.5 kPa) and even signs of fluid in the middle ears when summoned for retests. Five of them had a history of a recent URI. With one exception (group I), they all belonged to tubal function groups III and IV at the initial test. Their results of Pol_{ch} and Pcl_{ch} did not significantly differ from the results of the others ($p > 0.05$, Student's t -test). The children could be tested at the recall after one to

two months since they all recovered without intervention during this time. They were therefore not excluded from the follow-up.

DISCUSSION

The present results demonstrate that the muscular opening function of the Eustachian tube improves with age in otologically healthy children, which has not been verified earlier. The findings confirm the results of an earlier investigation in different age groups of children showing a better muscular opening function in older children than in younger ones (Bylander et al., 1981). Furthermore, from the present

Table IV. Successful (+) and unsuccessful (-) inflationary and deflationary manoeuvres in 39 normal children at initial test and retest 1 ½ years later

Time	Inflation		Deflation	
	+	-	+	-
Initial test	32	7	11	28
1 ½ years later	35	4	13	26

study it is seen that improvement was most obvious during pre-school ages (3–7 years), which is in good agreement with the distribution into tubal function groups in relation to age as reported in the previous study (Bylander et al., 1981). These findings also agree with Holborow's (1970), who in functional studies as well as in sections of the Eustachian tube from children of various ages found, that the critical period of tubal insufficiency extended up to about 7 years. The well-known drop in incidence of middle ear disease at about 7 years might also be related to the reported findings.

Longitudinal studies by screening tympanometry have also shown improvement in results with age and a higher tendency to normalization of middle ear pressures after the age of 7 (Brooks, 1976; Renvall et al., 1978; Fiellau-Nikolajsen, 1981; Thomsen & Tos, 1981).

There is a lack of longitudinal studies of the muscular opening function in otologically healthy children. However, several authors have made such studies of this function in children with MEE during the course of treatment with tympanostomy tubes (Silverstein et al., 1966; Westergaard, 1970; Holmqvist & Renvall, 1974; Briggs et al., 1976; Neel et al., 1977; Poulsen & Tos, 1977; Beery et al., 1979). The results of these investigations generally agree in that there is no significant improvement of the muscular opening function of the Eustachian tube during observation times from 6–30 months. However, despite persistent poor muscular opening function, it was reported that the ears healed satisfactorily and the middle ear pressures often normalized after treatment (Holmqvist & Renvall, 1974; Renvall, 1975; Neel et al., 1977; Poulsen & Tos, 1977). Since the impaired muscular opening function of the Eustachian tube is thought to be primarily involved in the pathogenesis of MEE (Bluestone et al., 1974; Holmqvist & Renvall, 1974) it seems somewhat contradictory that the ears healed without any observed change in this function. However this discrepancy might be due to the performance of the

tests as well as to the methods employed. As shown by Bylander et al. (1981), 33% of otologically healthy children improved when not only swallowings but also other equilibration techniques such as jaw movements were used. Of these 16% could not at all equilibrate by means of swallowings, but were able to do so by the other equilibration techniques. In most studies reported, the only equilibration technique used has been deglutitions, with or without water. In our opinion, the performance of the exhalation/inhalation test should also include a defined time during which the subjects are allowed to try to equilibrate, and this time should not be too short (Bylander et al., 1981). Furthermore, tests which imply an abrupt application of negative pressure in the middle ear might affect the outcome because of the "locking phenomenon" of the Eustachian tube described by Flisberg et al. (1963). Thus, it seems important to standardize the exhalation/inhalation tests in order to be able to make correct and impartial comparisons between different studies as well as to draw correct conclusions. Furthermore, a prerequisite for comparisons between results obtained in health and disease is a method by which it is possible to measure the Eustachian tube function on subjects with intact eardrums.

It is suggested by several authors that sufficient information on the Eustachian tube function is obtained by tympanometry (Brooks, 1976; Tos et al., 1977; Fiellau-Nikolajsen, 1980). Absence of a satisfactory relation between results obtained by tympanometry and the exhalation/inhalation test has been reported (Bluestone et al., 1974; Renvall, 1975) and was evaluated in favour of tympanometry by Poulsen & Tos (1977). It has also been claimed that tubal function tests including the exhalation/inhalation test provide more or less unreliable data varying from time to time (Magnusson, 1980). This does not agree with the very good long-term stability of the muscular opening function of normal adults demonstrated in the present study by our standardized exhalation/inhalation test. In addition Groth et al.

(1982) demonstrated a very good test-retest reliability of repeated exhalation/inhalation tests at the same session in normal adults. A correlation between poor muscular opening function and negative middle ear pressure was also shown in previous investigations (Bylander et al., 1981, 1982*a*), and the present results provide further evidence of this relationship since also the tympanometric recordings of middle ear pressures improved during the investigation.

The pressure opening and closing functions of the Eustachian tube did not change during the follow-up, which is in agreement with the results of an earlier study showing no difference in pressure opening and closing values between otologically healthy children and adults (Bylander et al., 1982*a*). The only earlier study in children reporting on longitudinal data of pressure opening and closing functions (Beery et al., 1979) showed that in 27 children (5–15 years) with recurrent or chronic otitis media with effusion, these functions did not change during an observation time of up to 30 months.

The response rate of inflationary and deflationary manoeuvres has been shown to be higher in older than in younger children (Bylander et al., 1982*b*). This was shown to be related to the magnitude of over- or underpressure created in the rhinopharynx in contrast to results reported by other authors, who found no correlation between the response rate and the magnitude of overpressure by Valsalva's manoeuvre (Cantekin et al., 1976) or the magnitude of underpressure by sniffing (Falk, 1980). In the present study an increased response rate of inflation and deflation was observed over time in the whole material. However, the results of deflation varied a great deal between the tests for individual children, in contrast to the stable results of the pressure closing function of the Eustachian tube in the individual child. This observation tends to show the pressure closing level as a more reliable, quantitative measure of the tubal closing function.

The improvement of the Eustachian tube function with age thus seems to involve only the muscular opening function supported by reports on changes of the anatomic configuration of the skull base, the facial cranium and of tubal and peritubal structures improving the muscular vectors (Graves & Edwards, 1944; Holborow, 1970; Ross, 1971). These are important for the muscular opening of the Eustachian tube. Other etiological theories have been put forward by Holborow (1975) and Misurya (1976), who suggested that the tubal opening muscles are activated by a pressure dependent reflex mechanism. This is supported by Eden (1981), who investigated neural connections between middle ear, Eustachian tube and brain, and by Guindi (1981), who found mechanoreceptors in the rhinopharynx and suggested that they probably play a part in a pressure sensor mechanism with a direct reflex control of the tubal opening muscles. Throughout this study it was observed that younger children, in contrast to older ones, never complained spontaneously or when asked when the pressure in the chamber was changed. One may speculate if small children lack the ability to "feel" the pressure differences across the eardrum necessary to initiate muscular opening of the tube. This would support findings of an immature neuro-muscular control system in small children. Conclusively, the improvement of the muscular opening function of the Eustachian tube might not only be due to anatomic changes during growth but also to a maturity process of the neuro-muscular reflex system.

It was difficult to select otologically healthy children because of the well-known high incidence of middle ear disease and URI during childhood. Also children with single attacks of acute otitis media before and/or during the follow-up and transient periods of underpressures or even signs of fluid in the middle ears during the observation period were therefore included. However, they all recovered within one or two months without intervention. These children, with few exceptions, had a

poor muscular opening function of the tube at the initial test. Furthermore, none of the children, not even those remaining in the poor tubal function groups III and IV, developed persistent middle ear disease during the follow-up. Thus, tubal muscular opening dysfunction alone does not seem to cause these conditions. Other pathogenic factors possibly aggravate a primary poor muscular opening function and the combination might explain the high incidence of MEE in children.

ZUSAMMENFASSUNG

Die Funktion der Ohrtrumpete wurde in einer Studie, die sich über eine Periode von 1½–3 Jahren erstreckte, mit verschiedenen Druckausgleichstesten bei 44 drei bis zwölf Jahre alten Kindern untersucht, bei denen die Ohren gesund waren. Die muskuläre Öffnungsfunktion der Ohrtrumpete verbesserte sich mit steigendem Alter signifikant. Die Verbesserung war im Vorschulalter (3–7 Jahre) am häufigsten. Die mit Tympanometrie gemessenen und auf die muskuläre Öffnungsfunktion bezogenen Mittelohrdrücke zeigten auch während der Beobachtungszeit eine Tendenz nach Normalisierung. Die Drucköffnungs- und Schließfunktionen, die Schließkraft der Tuba reflektieren, wurden während der Beobachtungszeit nicht verändert. Es scheint möglich zu sein, die muskuläre Öffnungsfähigkeit durch Anwendung des beschriebenen standardisierten Exhalations-/Inhalationstestes zu graduieren. Es wird angeführt, daß die Hauptursache für die schlechte muskuläre Öffnungsfähigkeit bei Kindern nicht nur von anatomischen Unterschieden der Schädelbasis, der Ohrtrumpete und ihren umgebenden Strukturen, sondern auch von der Unreife des neuromuskulären Systems unter der Kindheit abhängig ist.

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UPPER RESPIRATORY TRACT INFECTION AND EUSTACHIAN TUBE FUNCTION
IN CHILDREN

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Abstract. The Eustachian tube function was studied in 11 children (3-9 years of age) with and without upper respiratory tract infection (URI). During URI the active muscular opening function and the middle ear pressure deteriorated while the passive pressure opening and closing levels, reflecting tubal closing forces, increased. These findings may explain the high frequency of transient episodes of middle ear underpressure and middle ear effusion (MEE) in children. In children with a primary tubal hypofunction due to poor muscular opening function, URI may contribute to recurrent or persistent MEE.

INTRODUCTION

The interrelationship between Eustachian tube dysfunction, upper respiratory tract infection (URI) and middle ear effusion (MEE) is not clear. It is, however, generally accepted that tubal dysfunction is involved in MEE. It is also a common observation that MEE is often preceded by URI. Several studies have shown that URI affects the tympanometric recordings of middle ear pressure (Ferrer, 1974; Tos et al., 1979a, 1979b; Meistrup-Larsen et al., 1981; Hjort Sørensen et al., 1982). Tos et al. (1979a, 1979b) found that URI was the commonest cause of negative middle ear pressures and flat tympanograms in 1- and 2-year-old children and claimed that it is one of the "most frequent and dominant etiologic factors in Eustachian tube dysfunction and MEE in small children". In addition, they found that the more frequent or long-lasting attacks of URI, the worse tympanometric findings. Results from screening tympanometry have shown seasonal variations with high frequencies of fluid and underpressure in the middle ears during winter (Fiellau-Nikolajsen, 1979; Tos & Poulsen, 1979; Lildholdt, 1980), which by some authors was suggested to be caused by the higher frequency of URI in children during this season. Furthermore, children in public day-care centers have poor tympanometric findings more often than children cared for at home, which would also seem to be caused by the high frequency of URI in the former group (Fiellau-Nikolajsen, 1979; Meistrup-Larsen et al., 1981; Hjort Sørensen et al., 1982).

During a follow-up study of Eustachian tube function in otologically healthy children a few children developed transient large underpressures and signs of fluid in the middle ears in connection with URI (Bylander & Tjernström, 1982). This observation focused the interest on the possible effect of URI on the tubal function. The purpose of the present investigation was thus to determine if there were any differences in the Eustachian tube function between URI and non-URI periods in otologically healthy children.

MATERIAL AND METHODS

Eleven children with URI, 7 girls and 4 boys, aged 3-9 years, were selected for the present study. Prior to this investigation the children had participated in a study of otologically healthy children defined by a negative otologic history without recent URI and normal findings at ENT-examination including examination with Siegle's pneumatic otoscope, audiometry, and tympanometry.

The tests during URI were performed within 6 months after the non-URI examination. The criterion for participation during URI was a history, received from the parents, of present signs and symptoms of URI, and an ENT-examination showing nasal congestion often with serous and in a few cases even purulent secretion. Due to methodological limitations and ethical considerations children with flat tympanograms or too great underpressures (approximately more negative than -2.5 kPa) in the middle ear could not be included in this study.

The equipment and procedure of the different tubal function tests were identical with those described in detail in previous papers (Bylander et al., 1981, 1982a, 1982b) and will only be briefly summarized here.

The Eustachian tube function was measured using a pressure chamber for static and dynamic pressure changes with an impedance bridge as a measuring device. The following tests were performed:

1. *Middle ear pressure* by tympanometry.
2. *Exhalation/inhalation test*, i.e. "active" equilibration of static pressure differences across the eardrum after a decrease or an increase in chamber pressure of ± 1 kPa. Depending upon the results of equilibration of applied over- and underpressures (± 1 kPa), by swallowing and a method of free choice (Bylander et al., 1981), the subjects were distributed in tubal function groups I-IV according to Elner et al. (1971). Groups I and II were considered to correspond to good and groups III and IV to poor muscular opening function.
3. *Deflation test* in a pressure chamber. The change in chamber pressure required to induce an overpressure in the middle ear forcing the tube open was called the pressure opening level

(Pol_{ch}). The residual overpressure in the middle ear when the tube closes after the pressure opening was called the pressure closing level (Pcl_{ch}).

4. *Inflationary manoeuvres*. The subject was instructed to perform Valsalva's manoeuvre and mouth-to-nose inflation. The latter test was performed with a nose olive connected to a catheter held in the mouth. Those who could build up a positive pressure in the middle ear by either manoeuvre were called responders to inflation. If the first manoeuvre was unsuccessful the subject was instructed to try again twice. The pressure closing level (Pcl_{rh}), i.e. the residual overpressure in the middle ear after a successful manoeuvre, was also recorded.
5. *Deflationary manoeuvres*. The subject was instructed to inspire vigorously with one nostril connected to the pressure transducer, the other open (sniffing) or closed (reversed Valsalva's manoeuvre). Those who could create a negative pressure in the middle ear by either manoeuvre were called responders to deflation. Three trials of each manoeuvre were allowed.

RESULTS

Muscular opening function by the exhalation/inhalation test

The distribution of the muscular opening function during non-URI and URI periods expressed in tubal function groups I-IV is given in Table I. The tubal function deteriorated during URI in all 11 children, except in 2, who already had a poor muscular opening function (groups III and IV). The change was significant ($p < 0.01$, Sign test*).

Pressure opening and closing functions by deflation in a pressure chamber

Table II gives the pressure opening levels (Pol_{ch}), the pressure closing levels (Pcl_{ch}), and the difference between these variables (Pol_{ch} minus Pcl_{ch}) assumed to express the luminal (mucosal) closing forces of the tube as measured on the two test

*Siegel, S. 1956. Nonparametric Statistics, Mc Graw-Hill

Table I. *Distribution of muscular opening function in tubal function groups I-IV in 11 otologically healthy children during non-URI and URI periods.*

	Tubal function groups	URI				Total
		I	II	III	IV	non-URI
non- URI	I	-	-	4	-	4
	II	-	-	-	3	3
	III	-	-	1	2	3
	IV	-	-	-	1	1
	Total URI	-	-	5	6	11

Table II. *Pressure opening and closing levels by deflation in a pressure chamber (Pol_{ch} and Pcl_{ch}) and Pol_{ch} minus Pcl_{ch} in kPa in 11 otologically healthy children during non-URI and URI periods.*

	Pol_{ch}			Pcl_{ch}			$Pol_{ch} - Pcl_{ch}$		
	mean	SD	SEM	mean	SD	SEM	mean	SD	SEM
non-URI	3.65	± 0.86	± 0.26	0.95	± 0.39	± 0.12	2.70	± 0.62	± 0.19
URI	4.38	± 1.01	± 0.30	1.79	± 0.83	± 0.25	2.59	± 1.20	± 0.36
Difference non-URI-URI	-0.73	± 1.21	± 0.37	-0.84	± 0.65	± 0.20	0.11	± 1.56	± 0.47

occasions. As seen from the table, both mean Pol_{ch} and mean Pcl_{ch} increased during URI. The difference between URI and non-URI periods was significant for Pcl_{ch} ($p < 0.01$, Student's t-test, paired observations) but not for Pol_{ch} ($p > 0.05$, Student's t-test, paired observations). Neither was the change of Pol_{ch} minus Pcl_{ch} between URI and non-URI periods significant ($p > 0.05$, Student's t-test, paired observations). Figure 1 shows the individual results of Pol_{ch} and Pcl_{ch} in the 11 children with and without URI.

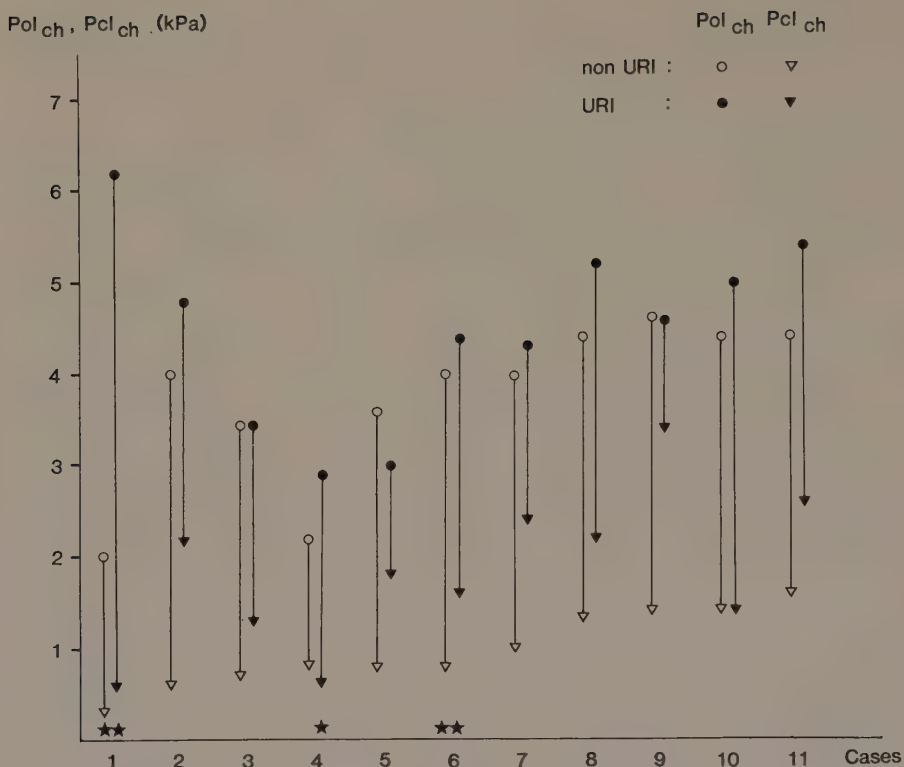


Fig. 1. Pressure opening and closing levels by deflation in a pressure chamber (Pol_{ch} and Pcl_{ch}) in 11 otologically healthy children investigated during non-URI (○,▽) and URI (●,▼) periods. * denotes ears with successful deflation.

Comments: The test-retest reliability of Pol_{ch} and Pcl_{ch}, based on the standard deviation of repeated measurements on the same session in 12 children, was presented in a previous paper (Bylander et al., 1982a), and the results were ± 0.17 kPa for Pol_{ch} and ± 0.25 kPa for Pcl_{ch}. To evaluate if a difference in results between URI and non-URI periods in the individual child was significant or not, the standard error for the difference between the measurements was calculated according to the formula $\sqrt{2(\overline{SD})^2}$. Of the 11 children in this study 6 had a significant increase of Pol_{ch} and 7 of Pcl_{ch}, which means that the increase was larger than two standard deviations of $\sqrt{2(\overline{SD})^2} = 0.50$ kPa and 0.70 kPa, respectively.

Middle ear pressure by tympanometry

The middle ear pressure measured by tympanometry deteriorated in most cases during URI (Fig. 2, Table III). The change was significant ($p < 0.05$, Student's t -test, paired observations).

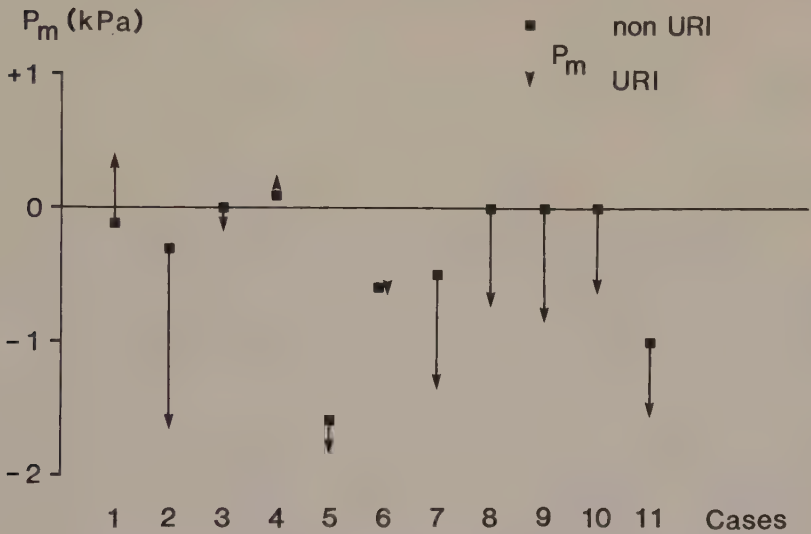


Fig. 2. Tympanometric recordings of middle ear pressures (P_m) in 11 otologically healthy children during non-URI (■) and URI (▼) periods.

Table III. Middle ear pressures in kPa in 11 otologically healthy children during non-URI and URI periods.

	mean	P_m SD	SEM
non-URI	-0.36	± 0.52	± 0.16
URI	-0.75	± 0.72	± 0.22
Difference non-URI-URI	0.39	± 0.50	± 0.15

Inflationary and deflationary manoeuvres

Without URI 9 of the 11 children had successful inflationary manoeuvres. During URI only 4 children responded to inflation. No statistical analysis was made of Pcl_{rh} during URI and non-URI periods since only 4 children could be compared. Two of the 11 children could deflate the middle ears without URI; during URI one more performed the manoeuvre successfully, and thus the response rate increased to 3 children. As seen from Fig. 1, responders to deflation (*) generally had low Pcl_{ch} also during URI.

DISCUSSION

It is generally believed that URI may cause impairment of the Eustachian tube function. There are, however, very few reports on URI affecting the pressure equilibrating capacity of the tube. Those studies were, however, performed on subjects with perforated eardrums (Rundcrantz, 1969; Bluestone et al., 1977).

In the present study of otologically healthy children a pressure chamber method (Ingelstedt et al., 1967), combined with the impedance technique, was used since it is suitable for studies on intact eardrums even in small children (Bylander et al, 1981, 1982a). Due to methodological limitations as well as medical and ethical considerations children with very great underpressures or even signs of fluid in the middle ears during URI could not be investigated. Thus, the material in this study was selected. Eleven children with no underpressures or moderate ones in the middle ears during URI were included.

Despite this selection the results indicate that URI affects the Eustachian tube function even in otologically healthy children. The muscular opening function during URI deteriorated in all 11 children except two, who had poor function also without URI. Rundcrantz (1969) measured the air volume passing through the Eustachian tube in 5 adults with dry central eardrum perforations and found similar results. During URI all 5 adults had decreased patency of the tube compared with non-URI. Investigating 20 children with tympanostomy tubes during treatment of MEE, Bluestone et al. (1977) also found deterioration of the muscular

opening function during URI. Furthermore, they found significantly increased opening and closing pressures (Pol and Pcl) in these children. In this report 6 of the 11 children developed a significant increase of Pol_{ch} and 7 children of Pcl_{ch} during URI. On the other hand, Beery et al. (1979) could not record any deterioration of the tubal function in children with tympanostomy tubes treated for MEE with non-purulent nasal congestion. They therefore suggested that only purulent nasal congestion may affect the tubal function.

The middle ear pressures measured by tympanometry, previously shown to be related to the muscular opening function (Bylander et al., 1981, 1982b), deteriorated in most cases during URI as well. This confirms the results of screening tympanometry in children with and without URI described by several authors (Ferrer, 1974; Tos et al., 1979a, 1979b; Hjort Sørensen et al., 1982).

Inflammatory changes in the nose during URI cause mucosal swelling, hypersecretion and often reduced mucociliary function. These changes are probably also present in the Eustachian tube. The increase of Pol_{ch} and Pcl_{ch} as well as the deterioration of the muscular opening function and, as a consequence, the middle ear pressure may therefore be attributed to these inflammatory changes of the tubal mucosa. The mucosal swelling resulting in a reduced tubal lumen is probably the dominant factor of the URI effects. The present findings are in accordance with the results obtained in tubal function tests of subjects in recumbency (Rundcrantz, 1969; Andréasson et al., 1976; Ivarsson et al., 1979; Groth & Tjernström, 1981) due to mucosal swelling, caused by an increased venous pressure of the head in this position (Jonsson & Rundcrantz, 1969).

The present findings indicate the importance of paying attention to the URI situation when evaluating the underlying mechanisms of tubal dysfunction. It may, however, be difficult to determine the criteria of non-URI due to the high frequency of common cold in children. In the present study a history of approximately two weeks without URI symptoms prior to the testing and no signs of URI on the clinical examination determined the non-URI status.

Since URI alone was shown to cause impairment of tubal function even in otologically healthy children, it is conceivable that URI is one of the dominating factors responsible for tubal dysfunction and MEE (Tos et al., 1979b). Furthermore, the great spontaneous and seasonal improvement of the tympanometry results, reported by several authors (Fiellau-Nikolajsen, 1979; Tos & Poulsen, 1979; Thomsen & Tos, 1981), might be explained by a normalized tubal function when the children recover from a URI.

In previous papers (Bylander et al., 1981, 1982a) it was demonstrated that otologically healthy children, also without URI, have a high frequency of poor muscular opening function, indicating a primary underlying hypofunction of the tube. This hypofunction will, however, be sufficient to maintain an adequate equilibrated middle ear pressure under normal conditions. But these children constitute a risk group, since URI as well as other etiologic factors may aggravate this hypofunction and contribute to persistent or recurrent MEE.

ZUSAMMENFASSUNG

Die Funktion der Ohrtrompete wurde bei elf Kindern (im Alter von 3-9 Jahren), bei denen die Ohren gesund waren, mit und ohne obere Luftwegsinfektion (OLI) untersucht. Die Muskelöffnungsfunktion und der Mittelohrdruck verschlechterten sich bei ÖLI, während Drucköffnungs- und Schliessungsfähigkeit, die die Schliessungskräfte der Tuba reflektieren, zunahm. Diese Resultate können die hohe Frequenz vorübergehender Episoden mit Unterdruck und Flüssigkeit im Mittelohr bei Kindern erklären. Bei Kindern mit einer primären Hypofunktion der Ohrtrompete auf Grund schlechter muskulärer Öffnungsfähigkeit kann OLI zu einem länger andauernden Zustand von Ohrenkatarrh führen.

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